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(54) Title: MULTIMERIC, RECOMBINANT UREASE VACCINE		
(57) Abstract <p>Methods and compositions are provided for preventing and/or treating <i>Helicobacter</i> (e.g., <i>H. pylori</i>) infection. The compositions of the invention, which are used in the methods of the invention (which include mucosal administration of the compositions), include compositions containing multimeric complexes of recombinant, enzymatically inactive <i>Helicobacter</i> urease in a pharmaceutically acceptable carrier or diluent; and compositions containing (a) a <i>Helicobacter</i> antigen, and (b) an antibiotic, an antisecretory agent, a bismuth salt, or a combination thereof.</p>		

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MULTIMERIC, RECOMBINANT UREASE VACCINEBackground of the Invention

This invention relates to methods and compositions  
5 for preventing and/or treating *Helicobacter* infection.

*Helicobacter* is a genus of spiral, gram-negative  
bacteria which colonize the gastrointestinal tracts of  
mammals. Several species colonize the stomach, most  
notably, *H. pylori*, *H. heilmanii*, *H. felis*, and *H.*  
10 *mustelae*. Although *H. pylori* is the species most  
commonly associated with human infection, *H. heilmanii*  
and *H. felis* have also been found to infect humans, but  
at lower frequencies than *H. pylori*.

*Helicobacter* infects over 50% of adult populations  
15 in developed countries, and nearly 100% in developing  
countries and some Pacific rim countries, making it one  
of the most prevalent infections of humans worldwide.  
Infection with *H. pylori* results in chronic stomach  
inflammation in all infected subjects, although the  
20 clinical gastroduodenal diseases associated with  
*Helicobacter* infection generally appear from several  
years to several decades after the initial infection. *H.*  
*pylori* is the causative agent of most peptic ulcers and  
chronic superficial (type B) gastritis in humans. *H.*  
25 *pylori* infection is also associated with atrophy of the  
gastric mucosa, gastric adenocarcinoma, and non-Hodgkin's  
lymphoma of the stomach (see, e.g., Blaser, *J. Infect.*  
*Dis.* 161:626-633, 1990; Scolnick et al., *Infect. Agents*  
*Dis.* 1:294-309, 1993; Goodwin et al.,  
30 *Helicobacter pylori*, *Biology and Clinical Practice*, CRC  
Press, Boca Raton, FL, 465 pp, 1993; Northfield et al.,  
*Helicobacter pylori*, *Infection*, Kluwer Acad. Pub.,  
Dordrecht, 178 pp, 1994).

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Summary of the Invention

We have shown that vaccine compositions containing multimeric, recombinant *Helicobacter* urease are effective in preventing and treating *Helicobacter* infection. In addition, we have shown that a composition containing *H. pylori* urease and a mucosal adjuvant, in combination with an antibiotic and a bismuth salt, is more effective at treating *Helicobacter* infection than any of these components alone, or any combinations of three or less of these components.

Accordingly, in a first aspect, the invention features a vaccine for inducing an immune response to *Helicobacter* (e.g., *H. pylori*) in a patient (e.g., a human patient) that (a) is at risk of developing, but does not have, a *Helicobacter* infection (a "protective" immune response), or (b) is already infected by *Helicobacter* (a "therapeutic" immune response). This vaccine contains multimeric complexes of recombinant, enzymatically inactive *Helicobacter* (e.g., *H. pylori*) urease, and a pharmaceutically acceptable carrier or diluent (e.g., sterile water or a 2% weight/volume sucrose solution). The vaccine may contain a multimeric complex containing eight Urease A subunits and eight Urease B subunits, a multimeric complex containing six Urease A subunits and six Urease B subunits, a multimeric complex containing four Urease A subunits and four Urease B subunits, or a mixture thereof. In addition, the vaccine may contain a mucosal adjuvant, such as the heat-labile enterotoxin of enterotoxigenic *Escherichia coli* (LT), a cholera toxin (CT), a *Clostridium difficile* toxin, or a subunit or derivative thereof lacking toxicity but still having adjuvant activity (e.g., a fragment, mutant, or toxoid), or a mixture thereof. For example, a fragment containing the 794 carboxyl-terminal amino acids of *C. difficile* Toxin A

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(see, e.g., Dove et al., supra, for the sequence of *C. difficile* Toxin A) may be used. Further, the multimeric complexes of recombinant, enzymatically inactive *Helicobacter* urease may be freeze-dried prior to use in the vaccines of the invention.

In a second aspect, the invention features a method of inducing a protective and/or therapeutic mucosal immune response to *Helicobacter* (e.g., *H. pylori*) in a patient (e.g., a human patient). In this method, a composition containing an immunogenically effective amount of multimeric complexes of recombinant, enzymatically inactive *Helicobacter* (e.g., *H. pylori*) urease is administered to a mucosal surface (e.g., an oral or intranasal surface; or to a rectal surface by, e.g., anal suppository) of the patient. The composition may contain a multimeric complex containing eight Urease A subunits and eight Urease B subunits, a multimeric complex containing six Urease A subunits and six Urease B subunits, a multimeric complex containing four Urease A subunits and four Urease B subunits, or a mixture thereof. The composition may be administered without gastric neutralization by, e.g., sodium bicarbonate.

In addition to the multimeric complexes of recombinant, enzymatically inactive *Helicobacter* urease, the composition used in this method may further contain a mucosal adjuvant. For example, the composition may contain the heat-labile enterotoxin of enterotoxigenic *Escherichia coli* (LT), a cholera toxin (CT), a *Clostridium difficile* toxin, or a subunit or derivative thereof lacking toxicity but still having adjuvant activity (e.g., fragments, mutants, or toxoids having adjuvant activity), or mixtures thereof. For example, a fragment containing the 794 carboxyl-terminal amino acids of *C. difficile* Toxin A (see, e.g., Dove et al., supra, for the sequence of *C. difficile* Toxin A) may be used.

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Further, the multimeric complexes of recombinant, enzymatically inactive *Helicobacter* urease in the composition may be freeze-dried prior to use in this method.

5 In a third aspect, the invention features a composition for treating *Helicobacter* (e.g., *H. pylori*) infection in a patient (e.g., a human). This composition contains (a) a *Helicobacter* (e.g., *H. pylori*) antigen (e.g., urease), and (b) an antibiotic, an antisecretory  
10 agent, a bismuth salt, or a combination thereof. An example of a *Helicobacter* urease antigen which may be used in this composition is one containing multimeric complexes of recombinant, enzymatically inactive *Helicobacter* urease, as is described above. Other  
15 *Helicobacter* antigens which may be used include, e.g., HspA, HspB, AlpA, AlpB, ClpB, and the antigen recognized by monoclonal antibody IgG 50 (see below). This composition may further contain a mucosal adjuvant (or a combination of mucosal adjuvants), such as those which  
20 are listed above.

Antibiotics which may be included in this composition include, but are not limited to, amoxicillin, clarithromycin, tetracycline, metronidazole, and erythromycin; and bismuth salts which may be included  
25 are, e.g., bismuth subcitrate and bismuth subsalicylate. Antisecretory agents which may be included in the composition are, e.g., proton pump inhibitors (e.g., omeprazole, lansoprazole, and pantoprazole), H<sub>2</sub>-receptor antagonists (e.g., ranitidine, cimetidine, famotidine,  
30 nizatidine, and roxatidine), and prostaglandin analogs (e.g., misoprostil or enprostil).

In a final aspect, the invention features a method for treating *Helicobacter* (e.g., *H. pylori*) infection in a patient (e.g., a human patient). In this method, a  
35 composition containing (a) a *Helicobacter* (e.g., *H.*

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pylori) antigen (e.g., the antigens listed above), and  
(b) an antibiotic, an antisecretory agent, a bismuth  
salt, or a combination thereof, is administered to the  
patient. Any standard mode of administration, or a  
5 combination of standard modes, may be employed. For  
example, mucosal administration (e.g., administration to  
an oral or intranasal surface, or administration to a  
rectal surface by, e.g., anal suppository) may be used.  
A composition administered to a mucosal surface in this  
10 method may further contain a mucosal adjuvant (or a  
combination of mucosal adjuvants), e.g., the mucosal  
adjuvants which are described above. Antibiotics,  
bismuth salts, and antisecretory agents which may be  
included in the composition used in this method are  
15 described above.

By "vaccine" is meant a composition containing at  
least one antigen (e.g., an antigen from a pathogenic  
microorganism, such as *H. pylori*) which, when  
administered to a patient, elicits or enhances an immune  
20 response to the antigen that is effective in the  
prevention of disease (e.g., disease caused by infection  
by the microorganism), or in the treatment of a pre-  
existing disease.

By "immunogenically effective amount" is meant an  
25 amount of an antigen (e.g., multimeric complexes of  
recombinant, enzymatically inactive *Helicobacter* urease,  
or any of the other antigens listed above) which is  
effective to elicit an immune response (e.g., a humoral  
or a mucosal immune response) when administered to a  
30 patient, such as a human patient.

By "*Helicobacter*" is meant any bacterium of the  
genus *Helicobacter*, particularly a *Helicobacter* which  
infects humans (e.g., *H. pylori*). By "urease" is meant  
an enzyme (e.g., *H. pylori* urease) which catalyzes the

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conversion of urea into ammonium hydroxide and carbon dioxide.

By "multimeric complex" is meant a macromolecular complex of polypeptides (e.g., urease polypeptides). The polypeptides may be associated in the complex by a variety of intermolecular interactions, such as covalent bonds (e.g., disulfide bonds), hydrogen bonds, and ionic bonds.

By "mucosal adjuvant" is meant a compound (e.g., an immunomodulator) which non-specifically stimulates or enhances a mucosal immune response (e.g., production of IgA antibodies). Administration of a mucosal adjuvant in combination with an immunogenic composition facilitates the induction of a mucosal immune response to the antigen in the composition.

By "antibiotic" is meant a compound derived from a mold or bacterium that inhibits the growth of other microorganisms.

Other features and advantages of the invention will be apparent from the following detailed description and from the claims.

#### Detailed Description

The drawings are first described.

##### Drawings

Fig. 1 is a diagram showing the restriction enzyme map of the 2.5 kb PCR product cloned from pSCP1. The numbers above the map indicate nucleotide positions using the first base pair (bp) of BL1 as nucleotide #1. Locations of ureA and ureB genes and the direction of transcription of these genes are shown. The locations of restriction enzyme cleavage sites are shown below the genes. The numbers next to the name of each restriction enzyme indicate the locations of the first base pair in the recognition sequence for the enzyme indicated.



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Fig. 2 is a diagram of the genetic map of the expression plasmid pORV214. The *ureA* and *ureB* genes are shown as open bars with arrows. The solid arrow and solid bar represent the T7 promoter and terminator sequences, respectively. Thin lines represent pBR322 DNA. The phage and plasmid origins of replication on the plasmid are shown by large shaded arrows, denoted "f1 origin" and "ori," respectively, and indicate the direction of DNA synthesis. The genes encoding kanamycin resistance (*kan*) and the lactose repressor (*lacI*) are shown as shaded bars. The *Bam*HI and *Eco*RI sites used for cloning the PCR product are indicated. Arrows within bars representing *lacI*, *ureA*, *ureB*, and *kan* genes indicate the direction of transcription.

Fig. 3 is a schematic representation of the nucleotide sequence of the *H. pylori* locus encoding the *ureA* and *ureB* genes, as well as the transcriptional regulatory sequences from pORV214 (SEQ ID NO:1). The predicted amino acid sequences of *ureA* (SEQ ID NO:2) and *ureB* (SEQ ID NO:3) are shown above the DNA sequence. Numbers to the left of the sequence correspond to nucleotide positions and those on the right indicate amino acid positions. The sequences corresponding to the PCR primers are underlined and the *Bam*HI and *Eco*RI sites used to clone the PCR product are indicated. The predicted transcriptional initiation site (G) and direction of transcription are shown with an arrow. The ribosomal binding site (RBS) is indicated. The sequences which regulate transcriptional initiation (T7 promoter and *lac* operator) and termination are underlined and labeled.

Fig. 4 is a graph showing analytical size exclusion HPLC for recombinant urease.

Fig. 5 is a series of graphs showing the bacterial score versus the levels of serum IgA, serum IgG, and

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fecal IgA antibodies from mice immunized with recombinant *H. pylori* urease and cholera toxin (CT).

Fig. 6 is a series of graphs showing the bacterial score versus the levels of serum IgA, serum IgG, and fecal IgA antibodies from mice immunized with recombinant *H. pylori* urease and enterotoxigenic *E. coli* heat-labile toxin.

Fig. 7 is a table showing the experimental protocol used for comparing intranasal and oral immunization routes for recombinant urease.

Fig. 8 is a series of graphs showing the serum IgG (Serum G), serum IgA (Serum A), fecal IgA (Fecal A), and salivary IgA (Sal A) levels in groups of mice treated according to the protocol illustrated in Fig. 7.

Fig. 9 is a table showing the experimental protocol used for comparing intranasal and intragastric immunization routes for recombinant urease.

Fig. 10 is a series of graphs showing the results of urease tests carried out on the mice treated according to the protocol illustrated in Fig. 9.

Fig. 11 is a graph showing that rUrease (10  $\mu$ g) given by the intranasal route with CT (5  $\mu$ g) is at least as effective as rUrease (25  $\mu$ g) given by the oral route with CT (10  $\mu$ g) in preventing infection with *H. felis*.

Fig. 12 is a graph showing that immunization of mice with rUrease + 10  $\mu$ g LT reduces or eradicates established *H. felis* infection. When these animals were reinfected with *H. felis*, they were protected against challenge.

Fig. 13 is a graph showing the mean antibody response of mice 4 and 10 weeks after therapeutic immunization with either recombinant *H. pylori* urease and CT, or CT alone.

Fig. 14 is a graph showing numbers of IgA antibody secreting cells in gastric mucosa of immunized and

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unimmunized mice before, and at intervals after, infection with *H. felis*.

Fig. 15 is a graph showing the clearance of *H. felis* infection in mice previously immunized with 5 recombinant *H. pylori* urease and CT.

#### Cloning of the ureA and ureB genes

The structural genes encoding urease, ureA, and ureB, have been cloned (Clayton et al., *Nucl. Acids. Res.* 18:362, 1990; Labigne et al., *J. Bacteriol.* 173:1920-1931, 1991), and the recombinant urease encoded by these genes has been purified (Hu et al., *Infect. Immun.* 60:2657-2666, 1992). For use in the present invention, urease was cloned from a clinical isolate of *H. pylori* (CPM630) obtained from a clinical specimen provided by 15 Dr. Soad Tabagchali, St. Bartholomew's Medical College, University of London. A genomic DNA library of strain CPM630 was prepared in the lambda phage vector EMBL3. Plaques were screened for reactivity with rabbit anti-*Helicobacter* urease polyclonal antibody, and a 20 single reactive plaque was isolated. This clone contained a 17 kb *SalI* fragment that encoded the ureA and ureB genes. The 17 kb fragment was subcloned onto pUC18 and designated pSCP1. A 2.7 kb *TaqI* fragment was subcloned (pTCP3) and completely sequenced. The 2.7 kb 25 *TaqI* fragment encoded both ureA and ureB.

The primers BL1 (CGG GAT CCA CCT TGA TTG CGT TAT GTC T; SEQ ID NO:4) and BL2 (CGG AAT TCA GGA TTT AAG GAA GCG TTG; SEQ ID NO:5) were used to amplify and clone a 2.5 kb fragment from pSCP1. BL1 and BL2 correspond to 30 nucleotides 2605-2624 of GenBank accession number M60398 (the BL1 primer) and nucleotides 2516-24998 of EMBL accession number X17079 (the BL2 primer). A restriction enzyme map of the 2.5 kb fragment PCR product is shown in Fig. 1. The 2.5 kb fragment contains the entire coding

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region of ureA and ureB, as well as translational start signals from *H. pylori* upstream of ureA.

#### Expression of recombinant urease

The purified 2.5 kb PCR fragment containing the  
5 genes encoding ureA and ureB was digested with *EcoRI* and  
*BamHI* and inserted into the expression vector pET24+  
(Novagen, Madison, Wisconsin) to produce the plasmid  
pORV214 (Fig. 2). pET24+ contains the *colE1* origin of  
replication, the filamentous phage (f1) origin of  
10 replication for single strand rescue, and the kanamycin  
resistance gene of Tn903. The fragment was inserted  
downstream of the T7 promoter, which provides  
transcription initiation for the urease genes. Lactose  
operator (*lacO*) sequences are present between the T7  
15 promoter and the cloning sites to provide inducible  
expression of the urease genes. A T7 transcription  
terminator sequence is located downstream of the cloning  
sites. The vector also contains the lactose repressor  
gene (*lacI*) to ensure complete repression of expression.  
20 Other sequences present in the vector are derived from  
pBR322, which served as the backbone for vector  
construction.

The initial ligation mixture, containing the 2.5  
kb PCR *EcoRI*-*BamHI* fragment and the pET24+ vector  
25 digested with *EcoRI* and *BamHI*, was used to transform  
XL1-Blue (Stratagene, La Jolla, CA) prepared by the  $\text{CaCl}_2$   
method. XL1-Blue is an *E. coli* strain that does not  
express T7 RNA polymerase. Kanamycin resistant colonies  
were directly screened by PCR using urease specific  
30 primers. Plasmid DNA from several positive colonies was  
extracted using Qiagen minispin columns (Qiagen,  
Chatsworth, CA) and checked for the correct restriction  
digestion pattern.

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Purified pORV214 DNA was used to transform the *E. coli* strain BL21-DE3 (Novagen, Madison, Wisconsin) prepared by the  $\text{CaCl}_2$  method. BL21-DE3 is an *E. coli* B strain that is lysogenized with lambda phage DE3, a recombinant phage that encodes T7 RNA polymerase under the control of the *lavUV5* promoter. BL21 is deficient in *lon* and *ompT* proteases, as well as the *hsdS<sub>B</sub>* restriction/modification system and *dcm* DNA methylation. DNA was prepared from kanamycin resistant colonies with Qiagen mini spin columns and screened by restriction enzyme analysis using *Bam*HI and *Eco*RI to confirm the presence of the plasmid. Urease expression was assessed by examination of BL21-DE3 (pORV214) cell lysates by SDS-PAGE and Western blot. Several positive clones had the correct restriction endonuclease digestion pattern and expressed urease.

A single clone containing pORV214 was selected, grown on LB plates containing kanamycin (50  $\mu\text{g/ml}$ ), harvested, and stored at  $-80^\circ\text{C}$  in LB containing 50% glycerol. A research cell bank was prepared by growing a sample from the glycerol stock on LB plates containing kanamycin, selecting an isolated colony, and inoculating a LB broth culture containing kanamycin. This culture was grown to  $\text{OD}_{600}$  of 1.0, pelleted, and resuspended in an equal volume of LB containing 50% glycerol. These research cell bank (RCB) aliquots (100  $\mu\text{l}$ ) were then stored at  $-80^\circ\text{C}$ . A master cell bank (MCB) was similarly prepared using an isolated colony from the research cell bank, and a manufacturer's working cell bank (MWCB) was prepared using an isolated colony from the MCB.

The MCB and MWCB cells were viable, kanamycin resistant, and displayed a normal *E. coli* colony morphology. T7 RNA polymerase expression and lambda phage lysogeny was confirmed using appropriate tests, which are well known in the art. Urease expression was

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IPTG-inducible in the MCB and MWCB cells, as determined by examination of cultures grown in the presence of IPTG, and analysis of lysates from these cell cultures on SDS-PAGE. Production of 60 kD and 29 kD proteins (UreB and UreA, respectively) by the MCB and MWCB cells increased with the incubation time.

Plasmid DNA was isolated from the MCB and MWCB cells and was tested by restriction enzyme analysis, restriction fragment length polymorphism (RFLP), and DNA sequence analysis to confirm plasmid structure. The MCB contained a plasmid with the appropriate restriction endonuclease digestion pattern with no deletions or rearrangements of the plasmid. Likewise, there were no differences between the RFLP fingerprint of pSCP1 and the RFLP fingerprints of plasmid DNA from MCB and MWCB, indicating that the urease genes had not undergone detectable (> 50 bp) deletions or rearrangements in the cloning process or in the manufacture of the cell banks.

The coding regions of ureA and ureB, and the sequences of the promoter and termination regions of the plasmid isolated from MCB cells, were sequenced. Sequencing reactions were performed using the Di-Deoxy Cycle Sequencing Kit, according to the manufacturer's instructions (Applied Biosystems, Inc., Foster City, CA), using fluorescent-labeled dideoxynucleotides. The sequences of the ureA and ureB genes, with predicted protein sequences, as well as the DNA sequences of flanking regions are shown in Fig. 3.

#### Large-scale production of recombinant urease

The fermentor(s) to be used was cleaned and sterilized according to approved procedures. The culture medium contained 24 g/L yeast extract, 12 g/L tryptone, 6-15 g/L glycerol, in RO/DI water. Since pORV214 was sufficiently stable in the absence of antibiotics, no

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and used as an antigen to produce polyclonal anti-urease antibodies, as well as mono-specific polyclonal anti-UreA, anti-UreB, and anti-urease holoenzyme antibodies.

5 Native *H. pylori* urease was purified using a modification of the procedure reported by Hu and Mobley (*Infect. Immun.* 58:992-998, 1990). *H. pylori* strain ATCC 43504 (American Type Culture Collection, Rockville, MD) was grown on Mueller-Hinton agar (Difco Laboratories, 10 Detroit, MI) containing 5% sheep red blood cells (Crane Labs, Syracuse, NY) and antibiotics (5 µg/ml trimethoprim, 10 µg/ml vancomycin and 10 U/ml polymyxin B sulfate) (TVP, Sigma Chemical Co., St. Louis, MO). Plates were incubated 3-4 days at 37°C in 7% CO<sub>2</sub> and 90% 15 humidity, and bacteria were harvested by centrifugation. The bacteria were suspended in water or 20 mM phosphate, 1 mM EDTA, 1 mM β-mercaptoethanol (pH 6.8) containing protease inhibitors, lysed by sonication and clarified by centrifugation. The clarified supernatant was mixed with 20 3 M sodium chloride to a final sodium chloride concentration of 0.15 M and passed through DEAE-Sepharose (Fast Flow). Active urease that passed through the column was collected, concentrated in a Filtron Macrosep 100 centrifugal filtration unit, and then passed 25 through a Superose-12 or Superdex 200 size exclusion column. Size-exclusion chromatography was performed using Pharmacia FPLC pre-packed columns. The fractions containing urease activity were pooled, concentrated, and further purified by FPLC anion-exchange chromatography on 30 a Mono-Q sepharose column prepacked by Pharmacia. The bound urease was eluted using a sodium chloride gradient. The fractions with urease activity were pooled and concentrated using Macrosep 100 centrifugal filters from Filtron Inc. For some lots, a final purification was

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achieved by analytical size-exclusion FPLC on Superose-12 columns.

Polyclonal antiserum to *H. pylori* urease was produced by immunizing three female New Zealand white rabbits with purified native *H. pylori* urease. The animals were pre-bled to confirm non-immune status and then immunized subcutaneously with 150  $\mu$ g urease in complete Freund's adjuvant. Two booster doses of 150  $\mu$ g each were administered subcutaneously 27 and 45 days later with Freund's incomplete adjuvant. After confirmation of the immune response by ELISA and Western blotting against purified urease, the animals were exsanguinated. The blood was clotted at 4°C overnight and serum was harvested by centrifugation. Serum IgG was purified by ammonium sulfate precipitation (50%) overnight at 4°C. The precipitate was resuspended in PBS and dialyzed to remove ammonium sulfate. The anti-urease titer of the IgG from each animal was found to be 1:10<sup>7</sup> and the antibodies from the three animals were pooled. The protein concentration was determined to be 17.3 mg/ml. Aliquots of 0.2 ml each were prepared and stored at -80°C.

Mouse polyclonal ascites against *H. pylori* urease holoenzyme ("MPA3") was prepared by injecting five mice subcutaneously with 10  $\mu$ g native urease holoenzyme in complete Freund's adjuvant on Day 0. The mice were boosted on Days 10 and 17, bled on day 24 to confirm anti-urease immune response, and boosted again on Day 26. On Day 28 the mice were injected intraperitoneally with Sarcoma 180 cells. A final intraperitoneal booster dose of 10  $\mu$ g urease was given on Day 31, and ascitic fluids collected seven days later.

The ascitic fluids were incubated for two hours at room temperature and then at 4°C for 16 hours; clots were disrupted by vortexing and removed by centrifugation at



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10,000 rpm for 10 minutes. After overnight incubation at 4°C in plastic tubes, the fluids formed solid clots. These were homogenized, diluted five-fold with PBS, and re-clarified by centrifugation at 10,000 rpm for 5 10 minutes. Thirty-six ml of diluted ascitic fluids were collected and frozen at -20°C in 300 µl aliquots. Western blot analyses confirmed that the antibody reacts with UreA and UreB subunits. An endpoint titer of 1:300,000 was achieved in ELISA against urease.

10 Mouse polyclonal ascites against *H. pylori* UreA ("MPA4") was prepared by injecting mice subcutaneously with native UreA subunit *H. pylori* urease isolated by electroelution from SDS-PAGE gels. Subsequent steps in the preparation of anti-ureA ascites were performed as 15 described above for generation of antibodies against the holoenzyme.

Mouse polyclonal ascites against native *H. pylori* UreB subunit ("MPA6") was prepared by injecting mice subcutaneously with native UreB isolated by 20 electroelution from SDS-PAGE gels. Subsequent steps in the preparation of anti-UreB ascites were performed as described above for generation of antibodies against the holoenzyme.

MAB71 is an IgA monoclonal antibody against 25 *H. felis* urease which recognizes a protective epitope on the B subunit. Preparation of this antibody is described in Czinn et al., *J. Vaccine* 11(6):637-642, 1993, and the hybridoma cell line which produces it was deposited with the ATCC and designated deposit number HB 11514. The 30 antibodies described above were used in Western blot experiments to characterize the purified recombinant *H. pylori* urease.

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SDS-PAGE and Western blot analysis of recombinant urease

Recombinant urease was first analyzed by SDS-PAGE (12.5%) run under reducing conditions. Two major protein bands (29 kD and 60 kD) and several lighter bands (approximately 38 kD) were evident. To identify the proteins in these bands, Western blots were performed using the anti-urease and anti-urease subunit antibodies described above. The 60 kD protein reacted with MPA3 (anti-urease holoenzyme) and MPA6 (anti-UreB), but not with MPA4 (anti-UreA). The 29 kD protein reacted with MPA3 (anti-urease holoenzyme) and MPA4 (anti-UreA), but not with MPA6 (anti-UreB). The lighter 38 kD band reacted with MPA3 (anti-urease holoenzyme) and MPA6 (anti-UreB), indicating that this protein is a portion of UreB.

Two faint high molecular weight (>150 kD) bands were evident in SDS-PAGE gels. Both bands reacted faintly with antibodies to both UreA and UreB, indicating that a minor portion of recombinant urease subunits form covalent units resistant to sulfhydryl reduction under the conditions used. No other protein bands were apparent in Coomassie-stained gels. Thus, all proteins detected in the purified product are either UreA, UreB, or a derivative of UreA or UreB.

The wet Coomassie-stained SDS-PAGE gel was scanned using an Ultrosan XL laser densitometer and a Gel Scan XL software program (Pharmacia-LKB Biotechnology, Piscataway, NJ). The densitometry data were consistent with a 1:1 molar ratio of the UreA:UreB subunits, as expected from the structure of native *H. pylori* urease. UreA and UreB accounted for more than 95% of the total protein present in the purified urease preparation. The estimated average value for the combined UreA + UreB peaks was  $95.2\% \pm 1.2\%$ .

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Analytical size-exclusion HPLC of purified recombinant urease

The purity and molecular composition of purified recombinant urease was determined by analytical size-exclusion high performance liquid chromatography. Chromatography was performed using a Beckman System Gold HPLC consisting of Pump 126, diode array dual wavelength detector 168, System Gold Software Version V7.11, Progell-TSK G4000SWXL (5 mm x 30 cm i.d.) column (Beckman Instruments, Brea, California), and SWXL guard column from Supel Co. Chromatography was performed under isocratic conditions using 100 mM phosphate, 100 mM sodium chloride buffer, pH 7.0. The column was calibrated using molecular weight markers from Pharmacia-LKB.

A typical HPLC separation profile of representative purified bulk sample is shown in Fig. 4. The purified urease product shows a prominent protein peak with a retention time between that of thyroglobulin (MW 669 kD) and ferritin (MW 440 kD). An apparent molecular weight of 550-600 kD was estimated based on a series of runs. This peak was tentatively designated as hexameric urease. The area of this hexameric urease was at least 70% of the total protein in different lots of product.

A second prominent protein peak with a lower retention time (higher molecular weight) was also detected. The area of this peak ranged from 5-20%. This peak, with a molecular weight >600 kD, was designated as octomeric urease. The total area of the octomeric plus hexameric urease peaks was over 90%.

These two characteristic peaks were isolated for further characterization. The two peaks were purified by HPLC from a preparation of reconstituted, freeze-dried urease and stored at 4°C for over one week. During

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storage for this period of time, octomeric urease increases while the hexameric form decreases. The separated peak fractions were analyzed by reducing SDS-PAGE and ELISA reactivity with monoclonal and polyclonal antibodies to urease. On SDS-PAGE, both peaks showed urease A and B bands in comparable ratios. In addition, both showed nearly identical immunoreactivity in ELISA with polyclonal anti-urease holoenzyme antibodies (MPA3) and a monoclonal anti-UreB antibody (MAB71).

Enzymatic (urea hydrolytic) activity of recombinant urease

Three methods were used to investigate the enzymatic activity of recombinant urease: urease-specific silver staining following electrophoresis, the pH-sensitive phenol red urea broth assay, and direct detection of ammonia. Urease-specific silver staining, described by deLlano et al. (Anal. Biochem. 177:37-40, 1989), is based on the reaction of urease with urea to produce ammonia. The reaction leads to a localized increase in pH which facilitates a photographic redox reaction leading to disposition of metallic silver. Enzymatic activity of native *H. pylori* urease was detected with only a 1.0 µg sample. In contrast, 20 µg purified recombinant urease exhibited no urease activity.

The pH-sensitive phenol red broth assay, which is well known in the art, is based on a change in pH due to ammonia generation as a result of urea hydrolysis. Urease activity was demonstrated with as little as 0.2 µg/ml purified *H. pylori* urease. In contrast, no urease activity was associated with purified recombinant urease, even at concentrations up to 750 µg/ml.

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Direct estimation of ammonia produced by hydrolysis of urea by urease was quantitated using Nessler's reagent (Koch et al., *J. Am. Chem. Society* 46:2066-2069, 1924). Urease activity of native *H. pylori* urease was detectable at a concentration of 1  $\mu\text{g/ml}$ . No activity was detected in assays containing up to 500  $\mu\text{g/ml}$  purified recombinant urease.

Based on the results of the urease-specific silver staining assay, the pH-sensitive phenol red broth assay, and direct estimation of ammonia, there is no detectable urease activity in the recombinant urease product.

Protective and therapeutic efficacy of purified recombinant urease

The *H. felis*-mouse model was used to test the efficacy of recombinant *H. pylori* urease in the prevention and treatment of *Helicobacter* infection. In this model, colonization of the stomach is readily established and is accompanied by gastric inflammation. This animal model is a well established system for the study of *Helicobacter*, and has been used extensively in laboratory investigations of the pathogenesis and treatment of *Helicobacter*-induced disease (see, e.g., Fox et al., *Infect. Immun.* 61:2309-2315, 1993; Goodwin and Worsley, *Helicobacter pylori, Biology and Clinical Practice*, CRC Press, Boca Raton, FL, 465 pp, 1993). Antigenic cross-reactivity between *H. pylori* and *H. felis* ureases allows use of the human vaccine candidate of the invention, recombinant *H. pylori* urease (rUre), to immunize animals infected, or subsequently challenged, with *H. felis*.

Both germ-free and conventional mice are susceptible to infection by *H. felis*, and develop life-long infection of the gastric epithelium, characterized by infiltration of inflammatory cells

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(Fox et al., *supra*). Dose response studies indicated that 100% of Swiss-Webster specific pathogen-free (SPF) mice become infected after a single oral challenge with  $10^4$  *H. felis*. Unless otherwise specified, a single dose of  $10^7$  was used to infect mice prior to therapeutic immunization or challenge mice after prophylactic immunization. A challenge of  $\sim 10^3$  times the infectious dose (I.D.<sub>90</sub>) with this *Helicobacter* represents a severe test of immunity.

#### 10 Assays for gastric infection

Several methods were used to detect *Helicobacter* in gastric tissue, including measurement of gastric urease activity, histologic examination, and culture of gastric tissue. Gastric urease activity was measured both qualitatively (presence or absence) and quantitatively. In the qualitative assay, stomachs were divided longitudinally into two halves from the gastroesophageal sphincter to the pylorus. One longitudinal piece, representing approximately 1/4 of the stomach, was placed in 1 mL of urea broth (0.1 g yeast extract, 0.091 g monopotassium phosphate, 0.095 g disodium phosphate, 20 g urea, and 0.1 g/L phenol red, pH 6.9). A distinctive color change (due to hydrolysis of urea by the enzyme, production of ammonia, and increased pH) after four hours incubation at room temperature indicated a positive result. For quantitative determinations, urease activity was determined by measuring absorbance at 550 nm of clarified urea broth incubated with whole stomach sections for 4 hours. This assay can detect as few as  $1-2 \times 10^4$  *H. felis*/0.1 g stomach tissue. This assay provides the same sensitivity as commercially available urease test kits used for human samples. Commercial kits have proven to be 100% specific and 90-92% sensitive compared to

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biopsy/histology (Szeto et al., *Postgrad. Med. J.* 64:935-936, 1988; Borromeo et al. *J. Clin. Pathol.* 40:462-468, 1987).

- Quantitative gastric urease assays by
- 5 spectrophotometric measurement of  $A_{550}$  were slightly more sensitive than visual determinations, and allowed estimation of the severity of infection. The cut-off value for a negative urease assay was defined as 2 standard deviations above the mean  $A_{550}$  for
  - 10 unchallenged/uninfected mice. The cut-off for a positive gastric urease assay was defined by 2 standard deviations below the mean  $A_{550}$  of unimmunized/challenged mice. Individual animals with low-grade infections had values intermediate between the negative and positive cut-offs.
  - 15 Visual grading of the urease response identified 11/12 (92%) of the positive samples.

- Histologic examination was performed by fixing stomach tissue in 10% formalin. The tissue was then embedded in paraffin, sectioned and stained with a
- 20 modified Warthin-Starry silver stain (Steiner's stain; Garvey, et al. *Histotechnology* 8:15-17, 1985) to visualize *H. felis*, and by hematoxylin and eosin stain to assess inflammatory responses in the tissue. Stained sections were examined by an experienced pathologist
  - 25 blinded to the specimen code.

- A semi-quantitative grading system was used to determine the number of bacteria and intensity of inflammation. The system used is a modification of the widely-accepted Sydney System for histological
- 30 characterization of gastritis in humans (Price, *Gastroenterol. Hepatol.* 6:209-222, 1991). Full-thickness mucosal sections were examined for the intensity of inflammation (increase in lymphocytes, plasma cells, neutrophils and presence of lymphoid follicles) and depth
  - 35 of infiltration of these cells and graded on a scale of

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0-4+. Grading the density of *H. felis* was accomplished by counting the number of bacterial cells with typical spiral morphology in an entire longitudinal section of gastric antrum (or corpus, if specified). Grades were  
5 assigned according to a range of bacteria observed (0 = none; 1+ = 1-20 bacteria; 2+ = 21-50 bacteria; 3+ = 51-100 bacteria; and 4+ = >100 bacteria).

#### Route of immunization

The effect of the route of administration upon the  
10 efficacy of the vaccine of the invention was examined in the mouse infection model. Six to eight week-old female specific pathogen free (SPF) Swiss-Webster mice were immunized with 200 µg recombinant *H. pylori* urease, either with or without 0.24 M NaHCO<sub>3</sub>. The recombinant  
15 urease was co-administered with 10 µg of cholera toxin (CT) as a mucosal adjuvant in all animals. Intragastric (IG) immunization was performed by delivering the antigen in 0.5 ml through a 20-gauge feeding needle to anesthetized animals. Oral immunization was performed by  
20 delivering the antigen in a 50 µl volume via a pipette tip to the buccal cavity of unanesthetized animals. For parenteral immunization, mice received 10 µg recombinant urease subcutaneously. Freund's complete adjuvant was used in the first subcutaneous immunization and Freund's  
25 incomplete adjuvant was used in subsequent boosters. For all routes of administration, a total of four doses of vaccine were administered at seven day intervals. Mice were challenged with 10<sup>7</sup> *H. felis* two weeks after the final vaccine dose, and necropsied two weeks after  
30 challenge. Gastric *H. felis* infection was detected by urease activity and histology. Protection in an individual mouse was defined by a negative urease assay and by a 0 or 1+ bacterial score by histology.



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Oral and intragastric administration of recombinant urease provided significant protection to challenge with *H. felis* (86-100%) (Table 1). Oral administration was effective both with and without co-administration of  $\text{NaHCO}_3$  with the recombinant urease. Intragastric administration was more effective when the recombinant urease was co-administered with  $\text{NaHCO}_3$ . Parenteral injection of the vaccine antigen was least effective. Immunized mice had significantly lower numbers of bacteria in gastric tissue after challenge than unimmunized controls. IgA antibody responses in serum and secretions were highest in mice immunized by the oral route. IgA antibodies were not elicited by parenteral immunization.

**Table 1**  
Recombinant *H. pylori* urease protects mice from challenge with *H. felis* after mucosal but not parental immunization

VACCINE	ROUTE OF IMMUNIZATION	ADJUVANT	BICARBONATE <sup>a</sup>	% PROTECTED (# PROTECTED/TOTAL)	
				UREASE ASSAY	HISTOLOGY <sup>b</sup>
PBS	oral	CT	No	0 (0/8)	0 (0/7)
200 µg rUre	oral	CT	No	100 (8/8)*	100 (7/7)*
200 µg rUre	oral	CT	Yes	100 (7/7)*	86 (6/7)*
200 µg rUre	Intragastric	CT	No	75 (6/8)*	38 (3/8)
200 µg rUre	Intragastric	CT	Yes	100 (7/7)*	100 (7/7)*
10 µg rUre	subcutaneous	Freund's	NA	38 (3/8)	25 (2/8)

<sup>a</sup> 0.24 M sodium bicarbonate was administered with vaccine and adjuvant.

<sup>b</sup> Percent protected (number mice with 0-1+ bacterial score/number tested).

\* p<0.01, Fisher's exact test, compared to mice given CT alone.

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The effect of immunization route upon the anti-urease antibody response was examined in mice. Swiss-Webster mice were immunized four times at ten day intervals with either: 1) 200  $\mu$ g recombinant purified *H. pylori* urease with 10  $\mu$ g CT, either with or without  $\text{NaHCO}_3$ , by oral administration; 2) 200  $\mu$ g recombinant purified *H. pylori* urease and 10  $\mu$ g CT with  $\text{NaHCO}_3$ , by intragastric administration; or 3) 10  $\mu$ g recombinant purified *H. pylori* urease with Freund's adjuvant by subcutaneous administration. One week after the fourth vaccine dose, mucosal and serum antibody responses were examined by ELISA using microtiter plates coated with 0.5  $\mu$ g of native *H. pylori* urease. Serum samples were diluted 1:100 and assayed for urease-specific IgA and IgG. Fresh fecal pellets, extracted with a protease inhibitor buffer (PBS containing 5% non-fat dry milk, 0.2  $\mu$ M AEBSF, 1  $\mu$ g aprotinin per ml, and 10  $\mu$ M leupeptin), were examined for fecal anti-urease IgA antibody. In some experiments, fecal antibody values were normalized for total IgA content determined by ELISA, with urease-specific fecal IgA expressed in  $A_{405}$  units/mg total IgA in each sample. Saliva samples were collected after stimulation with pilocarpine under ketamine anesthesia, and tested for urease-specific IgA at a dilution of 1:5.

No significant differences between antibody responses of mice immunized orally with or without  $\text{NaHCO}_3$  were detected, and the data were pooled for analysis. Mice given subcutaneous antigen developed urease-specific serum IgG, but serum and fecal IgA responses were elicited only when antigen was delivered by mucosal routes (oral or intragastric).

Mice immunized either orally or intragastrically with urease/CT were challenged with  $10^7$  *H. felis*. The pre-challenge antibody levels of orally or

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intragastrically immunized mice were correlated with histologically-determined bacterial scores after *H. felis* challenge (Fig. 5). Although IgA responses varied considerably between individual mice, on the whole, mice with higher serum and fecal IgA levels had reduced bacterial scores. These data indicate a role for IgA in suppression of, and protection from, infection. In contrast, serum IgG antibodies did not correlate with protection. While some protected mice had no detectable IgA antibodies, high levels of anti-urease IgA were not observed in animals that developed 4+ infections after challenge. These results not only support a role for mucosal immune responses in protection, but also suggest that immune mediators other than fecal and serum IgA play a role in eradication of *H. felis* infection.

These data show that: i) mucosal immunization is required for protective immunity; ii) the oral route of immunization is as effective, or more effective, than the intragastric route; iii) neutralization of gastric acid with  $\text{NaHCO}_3$  is required for effective intragastric (but not oral) immunization; and iv) parenteral immunization does not stimulate mucosal immunity or provide effective protection against challenge.

#### Schedule of immunization

Alternative immunization schedules were compared in order to determine the optimal immunization time-table to elicit a protective mucosal immune response. Swiss-Webster mice were immunized with 100  $\mu\text{g}$  recombinant urease in two, three, or four oral administrations, on a schedule shown in Table 2. The mucosal adjuvant CT (10  $\mu\text{g}$ ) was co-administered with the recombinant urease. As assessed by qualitative gastric urease assay, mice which received four weekly doses of antigen exhibited the highest levels of protection. Significant protection was

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also observed in mice given three doses of antigen on days 0, 7, and 21. Secretory IgA antibody responses were highest for mice given a total of four doses of recombinant urease at one week intervals. On the basis  
5 of protection ratio and antibody responses, the latter schedule was selected for further evaluation of the therapeutic and prophylactic efficacy of the vaccine.

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**Table 2**

Effect of different schedules of oral immunization on the prophylactic efficacy of urease vaccine

	GROUP	VACCINE DOSE/ IMMUNIZATION ( $\mu$ g) <sup>a</sup>	SCHEDULE (DAY OF IMMUNIZATION)	% PROTECTED (#/TOTAL) <sup>b</sup>
5	1	25	0, 7, 14, 21	70 (7/10)*
	2	50	0, 14	20 (2/10)
	3	50	0, 14	30 (3/9)
	4	33.3	0, 7, 21	40 (4/10)*
	5	50, 25, and 25	0, 7, 21	60 (6/10)*
10	6	None	0, 7, 14, 21	0 (0/10)

<sup>a</sup> Each group of mice were immunized orally with a total dose of 100  $\mu$ g recombinant *H. pylori* urease. CT (10  $\mu$ g) was used at each immunization, suspended in sterile distilled water, as the mucosal adjuvant. Group 6 received CT alone on the same schedule as group 1 and acted as the control. Groups 4 and 5 compared the effect of booster doses administered after two previous weekly immunizations.

<sup>b</sup> Percent protected (No. protected/No. tested) from a  $10^7$  challenge dose of *H. felis* two weeks post-immunization. Mice were sacrificed two weeks after challenge and protection was determined by the qualitative gastric urease assay.

\*  $p < 0.05$ , Fisher's exact test, compared to mice given CT alone.

The effect of different immunization schedules upon anti-urease antibody production was examined in mice. Antibody responses of mice immunized by one of the five different immunization schedules described in

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Table 2 were examined. Significant protection was observed in mice that received vaccine in four weekly doses or two weekly doses with a boost on day 21. Mice immunized by either of these two immunization  
5 schedules also had the highest average immune responses. The serum IgG and salivary IgA levels were highest in mice vaccinated on a schedule of four weekly doses.

#### Dose-protection relationship

Graded doses of recombinant urease were orally  
10 administered to mice to determine the minimal and optimal doses required for immunization and protection. Recombinant urease doses of 5, 10, 25, 50, and 100  $\mu$ g were administered to groups of eight mice by the oral route with 10  $\mu$ g CT in PBS. The antigen was given on a  
15 schedule of four weekly doses. As assessed by gastric urease and histologic bacterial score, significant protection of mice against challenge with *H. felis* was observed at all doses, with no significant differences between dose groups (Table 3). A dose response effect  
20 was clearly demonstrated in serum and mucosal antibody responses to recombinant urease, with the highest immune response at the 100  $\mu$ g dose level.

**Table 3**  
**Recombinant *H. pylori* urease at doses of 5 µg or more, protects mice against challenge with *H. felis***

VACCINE	ADJUVANT	ROUTE OF IMMUNIZATION	% PROTECTED <sup>A</sup> (# PROTECTED/TOTAL)	
			UREASE ASSAY	HISTOLOGY
none	10 µg CT	Oral	0 (0/7)	0 (0/7)
5 µg rUre	10 µg CT	Oral	86 (6/7)*	71 (5/7)*
10 µg rUre	10 µg CT	Oral	88 (7/8)*	63 (5/8)*
25 µg rUre	10 µg CT	Oral	100 (9/9)*	100 (9/9)*
50 µg rUre	10 µg CT	Oral	100 (8/8)*	88 (7/8)*
100 µg rUre	10 µg CT	Oral	100 (7/7)*	71 (5/7)*

<sup>A</sup> Percent protected (number mice with 0-20 bacteria per section/number tested) as determined by examination of silver-stained stomach sections.

\* Comparison to sham-immunized controls, Fisher's exact test, p≤0.02.



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The effect of recombinant urease dosage upon the anti-urease antibody response was examined in mice.

Swiss-Webster mice were immunized orally with graded doses (0, 5, 10, 25, 50, or 100  $\mu$ g) of recombinant urease plus 10  $\mu$ g CT as a mucosal adjuvant. IgA antibody responses in serum, feces, and saliva increased with the amount of recombinant urease administered. A 100  $\mu$ g dose of recombinant urease produced the highest antibody levels.

10 Swiss-Webster mice were orally immunized with graded doses (0, 5, 25, or 100  $\mu$ g) of recombinant urease, with 25  $\mu$ g enterotoxigenic *E. coli* heat-labile toxin (LT) as a mucosal adjuvant. One group of mice received 25  $\mu$ g recombinant urease and 10  $\mu$ g CT as a mucosal adjuvant for  
15 comparison. The mice were immunized orally 4 times every 7 days. Serum, feces, and saliva were collected 10 to 13 days after the last immunization and urease-specific antibody levels were determined by ELISA. Mice immunized with recombinant urease and LT developed serum and  
20 secretory antibodies against urease, with a clear dose-response effect. Strong salivary IgA antibody responses were observed in these animals.

Mice immunized with urease and LT as described above were challenged with  $10^7$  *H. felis* (see Fig. 4).  
25 The pre-challenge antibody responses of the urease/LT immunized mice were correlated with histologically-determined bacterial scores (Fig. 6). Fully protected animals (0 bacterial score) and those with low-grade infections (1+ bacterial score) had higher levels of  
30 antibodies in all compartments than animals with more severe infections. A few protected mice had no detectable immune response, suggesting that immune mediators other than IgA antibodies play a role in eradication of *H. felis* infection.

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The ability of high doses of recombinant urease to elicit a mucosal immune response was examined by administering intragastrically 1  $\mu$ g, 200  $\mu$ g, or 5 mg without adjuvant. One group of mice were

5 intragastrically immunized with 200  $\mu$ g urease plus 10  $\mu$ g CT as a control. Blood, feces, and saliva were collected 5 to 8 days after the last immunization. Animals were then challenged with  $10^7$  *H. felis* 10 days after the last immunization and sacrificed 14 days after challenge. *H.*

10 *felis* infection was detected by urease activity in stomach tissue.

High doses of recombinant urease elicited urease-specific serum IgG, but elicited comparatively low levels of mucosal antibodies as detected by ELISA.

15 Animals which exhibited a urease-specific serum IgG response were fully susceptible to *H. felis* challenge, indicating that serum IgG does not play a role in protection.

In summary, data from the above experiments

20 investigating different administration routes, administration schedules, and mucosal adjuvants demonstrate that, when administered with an effective mucosal adjuvant, oral or intragastric administration of recombinant urease at relatively low doses elicits

25 secretory IgA antibody and serum IgA and IgG responses. Secretory IgA antibody provides protection, while serum IgG responses do not. When protection is measured by histological bacterial counts, animals with higher IgA antibody titers were fully protected, or had

30 significantly reduced infections, as compared to animals with lower IgA antibody titers. Animals which did not exhibit detectable IgA antibody levels developed severe infections after challenge. Antibody responses were dose-dependent and differed by the schedule of

35 administration of antigen. The highest levels were

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achieved at antigen doses of 100-200  $\mu$ g. Administration of four doses of antigen at one week intervals provided the optimal schedule for immunization. An additional administration route, intranasal, was investigated, as follows.

Intranasal vaccination with recombinant urease

Swiss Webster mice were immunized either orally or intranasally (IN) with recombinant urease or formalin-fixed urease. The amounts of antigen and adjuvant, routes of administration (IN or oral), and immunization schedules are shown in Fig. 7. The formalin-fixed urease (Form-ure) was prepared according to the following protocol:

- (1) a vial containing 1 mg recombinant urease is reconstituted with 150  $\mu$ L of RO/DI water;
- (2) 50  $\mu$ L of formalin (37% formaldehyde), diluted 1:1000 in RO/DI water, is added to the vial (final concentration of urease is 5 mg/ml); and
- (3) the vial is incubated at 35°C for 48 hours.

Serum IgG, IgA, fecal IgA and salivary IgA responses in IN + CT group were higher than the oral + CT group, despite higher doses of rUrease and adjuvants that were used for oral immunization (Fig. 7 and Table 4). Protection was measured by the urease test, as well as by determining bacterial scores on stomach tissues of sacrificed animals. One hundred percent protection was found in the IN group, as compared to 80% in the oral group, when protection was assayed by urease test. Seven of eight of the orally immunized mice were positive for bacteria on their stomach tissues, whereas only 1/10 of the mice in the IN group were positive for bacteria (see groups 3 and 6 in Table 4 and Fig. 8).

In a second experiment, mice were immunized either intragastrically (IG) or intranasally with rUrease co-

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administered with LT as mucosal adjuvant (see Fig. 9 for details of the experiment and the immunization schedule). In this experiment, serum IgG, serum IgA, and salivary IgA responses in the IN + LT group were higher than in 5 the IG + LT group, despite higher doses of antigen and adjuvant that were used for IG immunizations (Fig. 10 and Table 5, groups 4 and 8). Mice in the IN + LT group were fully protected against *H. felis* challenge (10/10 compared with 3/9 untreated group), as determined by 10 urease test (see groups 4 and 5 of Table 5).

**Table 4**  
**Intranasal immunization with recombinant urease and cholera toxin**

Mouse #	Urease treatment	route/adjuvant	serum IgG	serum IgA	fecal IgA	salivary IgA	four hours urease	Bact.	Path.
1A1	10 µg/HCHO	IN/none	3.398	3.318	3.377	3.339	+		
1A2			3.119	3.218	0.786	3.249	+		
1A3			2.967	2.535	0.893	3.153			
1A4			3.064	2.390	1.065	3.311	+		
1A5			3.009	2.647	0.617	3.244	+		
1B1			2.994	2.068	0.497	3.329	-		
1B2			3.099	2.611	-0.010	3.235	+		
1B3			3.306	1.823	0.323	3.295	+		
1B4			3.424	2.931	0.522	3.372	+		
1B5			3.175	0.832	0.803	2.439	+		
2A1	10 µg	IN/none	3.021	2.562	2.090	3.204	+		
2A2			2.971	2.806	1.475	3.304	+		
2A3			2.894	1.943	0.584	3.288	+		
2A4			2.918	2.804	2.291	3.363	+		
2A5			2.926	3.264	0.118	3.418	+		
2B1			3.220	3.505	1.634	3.415	+		
2B2			3.383	2.708	0.410	3.336	+		
2B3			3.092	1.814	0.411	3.253	+		
2B4			3.033	3.090	2.672	3.266	+		

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2B5				3.055	2.076	1.193	3.263	+		
3A1	10 µg	IN/CT		2.969	0.405	0.192	1.670	-	0	2
3A2				2.871	0.097	0.154	0.526	-	0	2
3A3				2.984	0.677	0.081	0.473			
3A4				3.092	0.563	1.824	3.398	-		
3A5				3.335	0.256	1.052	0.587	-	1	2
3B1				3.013	0.148	0.142	0.586	-	0	2
3B2				3.068	0.388	0.867	2.410	-	0	2
3B3				3.008	0.255	0.468	0.778	-	0	2
3B4				2.908	0.985	1.086	1.172	-	0	2
3B5				2.879	0.186	1.904	1.317	-	0	2
4A1	100 µg/HCHO	oral/none		-0.006	0.024	0.021	0.009	+		
4A2				0.050	0.097	0.079	0.041	+		
4A3				0.001	0.097	0.056	-0.019	+		
4A4				3.195	0.598	0.190	2.097	+	0	3
4A5				1.271	0.027	0.034	0.010	+		
4B1				0.096	0.045	0.165	0.309	+		
4B2				0.021	0.033	0.043	0.059	+		
4B3				1.109	0.055	0.080	0.019	+		
4B4				0.006	0.022	0.083	0.017	+		
4B5				0.013	0.027	0.039	0.010	+		

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5A1	100 µg/--	oral/none	0.032	0.042	0.151	0.030	+		
5A2			0.756	0.077	2.957	0.156	+		
5A3			2.362	0.075	0.104	0.262	+		
5A4			0.012	0.034	0.146	0.065	+		
5A5			0.011	0.035	0.163	0.013	+		
5B1			0.012	0.042	0.089	0.017	+		
5B2			0.017	0.017	0.076	0.049	+		
5B3			1.583	0.058	0.058	0.182	+/-		
5B4			0.602	0.030	0.093	0.093	+		
5B5			1.672	0.059	0.060	0.093	+		
6A1	25 µg/--	oral/CT	0.698	0.267	0.076	0.387	-	1	2
6A2			2.139	0.065	0.089	0.206	-	1	2
6A3			0.006	0.013	0.098	0.011	-	3	2
6A4			2.957	0.354	0.185	2.999	-	1	2
6A5			0.011	0.019	0.042	0.026	-	0	2
6B1			0.000	0.022	0.041	0.005	-	1	2
6B2			0.009	0.002	0.067	0.069	-	2	2
6B3			0.320	0.022	0.041	0.048	+	4	2
6B4			0.010	0.009	-0.021	0.023	+	4	2
6B5			2.633	0.090	0.047	0.647	-	1	2
7A1	none		0.011	0.018	0.074	0.019	+	4	1

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7A2			0.007	-0.025	0.042	-0.004	+	4	2
7A3			0.000	0.019	0.082	0.018	+	4	2
7A4			0.004	0.028	0.024	-0.002	+	4	2
7A5			0.011	0.005	0.041	0.029	X		
7B1			0.019	0.004	0.089	-0.005	+	4	1
7B2			0.006	-0.003	-0.009	0.008	+	4	2
7B3			0.006	0.024	0.066	0.167	+	4	2
7B4			0.015	0.018	0.063	0.018	+	4	1
7B5			0.007	0.023	0.111	0.011	+		
plate 1		controls							
+			2.265	3.280	1.651	3.315			
-			-0.010	0.040	0.065	0.056			
plate 2		controls							
+			1.969	3.289	1.700	3.298			
-			-0.001	0.034	-0.004	0.019			



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Table 5

Intranasal immunization with recombinant urease and LT

	Urease				2 week sacrifice
Mouse #	Treatment	serum IgG	serum IgA	salivary IgA	Absorbance <sub>550</sub>
1AN	25 $\mu$ g 5x IN	3.530	0.350	0.340	0.802
1AL	200 $\mu$ g 2x IG	3.263	0.154	1.544	0.768
1AR		3.231	0.630	0.204	0.805
1ALL		3.233	0.318	0.251	0.806
1BN		3.344	0.401	0.112	0.726
1BL		3.322	0.724	2.015	0.168
1BR		3.424	0.225	0.426	0.748
1BLL		3.285	0.591	0.719	0.807
1BRR		3.262	0.141	0.202	0.675
2AN	25 $\mu$ g 5x IN	3.164	0.054	0.014	0.814
2AL	200 $\mu$ g 1x IG	3.232	0.231	0.747	0.823
2AR		3.236	0.981	0.412	0.695
2ALL		3.303	0.122	0.832	0.813
2BN		3.357	0.690	0.993	0.747
2BL		3.264	1.002	0.840	0.704
2BR		3.284	1.377	.0934	0.161
2BLL		3.241	.0458	0.191	0.748

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2BRR		3.280	0.129	0.134	0.720
3AN	25 $\mu$ g 2x IN	0.165	0.031	0.001	0.791
3AL	200 $\mu$ g 2x IG	3.364	0.332	0.356	0.824
3AR		1.731	0.031	-0.003	0.810
3ALL		3.321	0.450	0.541	0.798
3ARR		3.358	0.158	0.001	0.675
3BN		3.199	0.276	0.212	0.820
3BL		3.174	2.463	2.838	0.839
3BR		3.274	0.607	1.517	0.481
3BLL		3.284	1.279	2.593	0.829
3BRR		3.254	0.427	1.684	0.852
4AN	25 $\mu$ g 4x IN	3.375	0.118	0.212	0.111
4AL	with 2 $\mu$ g LT	3.482	0.346	0.546	0.107
4AR		3.330	3.237	3.302	0.109
4ALL		3.343	3.067	3.229	0.103
4ARR		3.220	1.625	2.156	0.106
4BN		3.287	1.263	2.943	0.224
4BL		3.305	0.496	2.029	0.139
4BR		3.283	0.809	2.307	0.114
4BLL		3.313	1.019	3.346	0.106
4BRR		3.474	0.674	1.683	0.119

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5AN	none	0.075	0.023	0.001	0.126
5AL		0.005	0.016	-0.002	0.881
5AR		0.011	0.008	-0.001	0.839
5ARR		0.005	0.007	0.000	0.834
5BN		0.033	0.016	0.001	0.134
5BL		0.013	0.009	0.004	0.814
5BR		0.025	0.014	0.007	0.833
5BLL		0.028	0.019	0.008	0.155
5BRR		0.095	0.012	0.003	0.818
6AN	25 $\mu$ g 5x IN	3.353	0.680	0.498	
6AL	200 $\mu$ g 1x IG	3.470	0.248	0.100	
6AR		3.387	1.236	0.741	
6ALL		3.362	0.409	0.322	
6ARR		3.244	1.036	1.056	
6BN		3.211	2.749	2.014	
6BL		3.286	0.360	0.328	
6BR		3.269	0.749	1.882	
6BLL		3.347	0.275	0.030	
6BRR		3.321	0.311	0.989	
7AN	25 $\mu$ g 4x IN	3.415	0.756	2.584	
7AL	with 2 $\mu$ g LT	3.428	3.080	3.287	

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7AR		3.249	2.054	3.188	
7ALL		3.269	1.010	3.240	
7ARR		3.255	0.713	3.243	
7BN		3.310	3.081	3.274	
7BL		3.439	2.298	3.222	
7BR		3.359	1.026	1.757	
7BLL		3.370	1.441	3.025	
7BRR		3.330	0.689	1.169	
8AN	200 $\mu$ g 4x IG	0.281	0.031	0.000	
8AL	with 10 $\mu$ g LT	3.234	0.925	1.872	
8AR		3.285	0.827	2.751	
8ALL		3.313	0.547	0.395	
8ARR		3.363	0.382	1.144	
8BN		3.407	1.189	1.880	
8BR		3.315	1.608	2.536	
8BLL		3.271	0.438	0.599	
9AN	none	0.011	0.003	0.000	
9AL		0.017	0.005	0.001	
9AR		0.007	0.002	0.001	
9ALL		0.011	0.013	0.000	
9ARR		0.006	0.019	-0.002	

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9BN		0.017	0.010	-0.001	
9BL		0.020	0.008	-0.002	
9BR		0.031	0.012	-0.002	
9BLL		0.005	0.016	0.005	
9BRR		0.019	0.011	0.000	

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Further support for the efficacy of intranasal immunization is shown in Fig. 11. Briefly, this experiment showed that rUrease (10  $\mu$ g), administered by the intranasal route with CT (5  $\mu$ g), is at least as effective as rUrease (25  $\mu$ g) given by the oral route with CT (10  $\mu$ g) in preventing infection with *H. felis*.

#### Selection of a mucosal adjuvant

*E. coli* heat-labile toxin (LT) is a multisubunit toxin which is closely related, both biochemically and immunologically, to CT. Because the toxicity of LT is lower than CT, LT is a practical mucosal adjuvant for use in humans (Walker and Clements, *Vaccine Res.* 2:1-10, 1993).

Mice were orally immunized with 5  $\mu$ g, 25  $\mu$ g, or 100  $\mu$ g recombinant urease and 25  $\mu$ g recombinant LT (Swiss Serum Vaccine Institute, Berne, Switzerland) for a total of four weekly doses. Control mice received LT only or 25  $\mu$ g urease vaccine with CT. Mice were challenged two weeks after the fourth dose and necropsied two weeks after challenge.

Gastric urease assays indicated significant protection or suppression of the infection in immunized animals at all vaccine doses (Table 6). Histological assessment confirmed significant reductions in bacterial scores in mice which received  $\leq 5$   $\mu$ g urease and LT. Protection was directly correlated with dose as determined by both gastric urease assay and histological examination, with the highest protection conferred by 100  $\mu$ g of recombinant urease co-administered with LT. Antibody determinations confirmed a dose-response relationship, with highest mucosal immune responses at the 100  $\mu$ g dose. When recombinant urease was administered at equivalent doses (25  $\mu$ g), LT was superior to CT as a mucosal adjuvant. These data indicate that

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while CT enhances the mucosal immune response to orally administered recombinant urease, LT is a better mucosal adjuvant and is thus the preferred over CT for co-administration with recombinant urease.

5 Table 6

E. coli heat-labile enterotoxin (LT) as a mucosal adjuvant for immunization with recombinant H. pylori urease

	VACCINE	ADJUVANT	% PROTECTED (# PROTECTED/TOTAL) <sup>a</sup>	
			UREASE ASSAY	HISTOLOGY
10	None	25 µg LT	0 (0/9)	0 (0/9)
	25 µg rUre	10 µg CT	70 (7/10)*	60 (6/10)*
	5 µg rUre	25 µg LT	787 (7/9)*	56 (5/9)*
	25 µg rUre	25 µg LT	90 (9/10)*	80 (8/10)*
	100 µg rUre	25 µg LT	100 (8/8)*	100 (8/8)*

15 <sup>a</sup> Percent protected (number of mice with negative urease assay or bacterial score 0-1+/number tested) determined by bacterial scores of silver-stained stomach sections.

\* Comparison to sham-immunized controls, Fisher's exact test, p<0.03.

20 To determine the adjuvant activity of lower doses of LT, mice were orally immunized with 25 µg of recombinant urease administered with 1, 5, 10, or 25 µg of LT. Similar protection ratios and antibody responses were observed at all LT doses.

25 Several studies were performed to assess adjuvants other than CT and LT, and to determine whether the requirement for a mucosal adjuvant could be eliminated by administration of antigen alone at a high dose. Cholera toxin B subunit (CTB) was compared with CT as a mucosal  
30 adjuvant for urease immunization. No protective effect

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was observed when 200  $\mu$ g urease was co-administered intragastrically with 100  $\mu$ g CTB (Calbiochem, La Jolla, CA) in 0.24 M sodium bicarbonate, whereas the same amount of urease with 10  $\mu$ g CT gave 100% protection, as  
5 determined by gastric urease activity.

An orally-active semi-synthetic analogue of muramyl dipeptide, GMDP, (N-acetylglucosaminyl-(b1-4)-N-acetyl-muramyl-L-alanyl-D-isoglutamine), was co-administered  
10 with 25  $\mu$ g urease at doses of 2, 20, and 200  $\mu$ g. GMDP co-administered with recombinant urease failed to protect mice against *H. felis* challenge.

Large doses (200  $\mu$ g, 1 mg, or 5 mg) of recombinant urease with or without CT were intragastrically  
15 administered to mice once a week for four weeks. The intragastric route was required because volumes for high antigen doses exceeded those that could be given orally in a reproducible fashion.  $\text{NaHCO}_3$  was co-administered to neutralize gastric acid. A total of four doses of  
20 antigen were administered at ten day intervals. Blood, feces, and saliva were collected five to eight days after the last immunization. Animals were challenged with  $1 \times 10^7$  *H. felis*, and infection was determined by urease activity in stomach tissue.

25 In the absence of CT, high antigen doses did not confer protection against *H. felis* challenge, whereas controls given 200  $\mu$ g of recombinant urease with CT were significantly protected (Table 7). Urease-specific serum IgG was induced at the high recombinant urease doses  
30 without adjuvant, but serum, fecal, and salivary IgA responses were absent or minimal. Histological examination of coded specimens from animals given 5 mg doses of urease revealed no differences in bacterial scores or leukocytic infiltrates, compared with  
35 sham-immunized animals.



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Table 7 A mucosal adjuvant facilitates protection by recombinant urease

Vaccine	Adjuvant	% protected (# protected/ tested)	Mean antibody levels (±SD) before challenge <sup>a</sup>			
			Serum IgG	Serum IgG	Fecal IgA	Salivary IgA
none	PBS	0 (0/5)	0.01 (±0.00)	0.03 (±0.07)	0.01 (±0.0 2)	0.02 (±0.03)
200 µg rUre	10 µg CT	88 (7/8)*	>2.97 (±1.84)	>1.02 (±1.41)	0.16 (±0.1 4)	0.59 (±0.73)
200 µg rUre	none	0 (0/9)	>2.06 (±1.98)	0.07 (±0.11)	0.02 (±0.0 2)	0.06 (±0.13)
1 mg rUre	none	0 (0/9)	>3.28 (±1.48)	0.12 (±0.17)	0.02 (±0.0 3)	0.18 (±0.40)
5 mg rUre	none	0 (0/9)	>2.68 (±1.98)	>0.22 (±0.17)	0.02 (±0.0 2)	0.08 (±0.11)

<sup>a</sup> Mean (±SD) urease-specific serum IgG or IgA expressed as A<sub>405</sub> units of serum (diluted 1:100), fecal extract (diluted 1:20), or saliva (diluted 1:5). Means are shown as > when individual values of 4.0 (the maximum A<sub>405</sub> reading) were included in calculating the mean values.

\* Comparison to sham-immunized controls, Fisher's exact test, p=0.005.

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Therapeutic immunization of mice with *H. felis* gastritis

The efficacy of the recombinant urease vaccine in treating *Helicobacter* infection in mice was evaluated by intragastrically infecting Balb/c mice with  $10^7$  *H. felis*, and, four weeks after infection, orally administering to the infected mice four weekly doses of 100  $\mu$ g recombinant urease with 10  $\mu$ g LT. Control mice received LT only (Fig. 12).

Ten of the mice in each group were necropsied four weeks after the final immunization for examination of the degree of *Helicobacter* infection by quantitative gastric urease. Nine out of ten Balb/c mice were free from infection, as measured by quantitative urease assay, whereas all controls were infected.

At four weeks, twelve animals receiving LT and 40 animals receiving urease + LT were reinfected with *H. felis*. Ten weeks after the challenge, the animals were sacrificed to determine the extent of infection by quantitative urease assay. Of nine animals which were given urease + LT, but not reinfected, 5 were still clear of infection (57%), as determined by gastric urease activity. All twelve LT-treated animals which were re-challenged were infected. Thirty-seven of the 40 mice (93%) which were given urease + LT, and then re-challenged with *H. felis*, were protected as determined by reduced gastric urease activity. This experiment shows that urease vaccination not only eradicates an existing *Helicobacter* infection, but also protects the host against reinfection.

Five of fourteen (36%) immunized Swiss-Webster mice were cured or had reduced infections, whereas all control animals were infected, although the differences in infection ratios between groups was not significant ( $p=0.26$ , Fisher's exact test, two-tailed). Infection in Swiss-Webster mice was more severe than in Balb/c mice,

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as measured by higher mean gastric urease activity in unimmunized animals ( $p < 0.0001$ , one-way ANOVA), possibly explaining the lower cure rates in Swiss-Webster versus Balb/c mice. Differences in susceptibility of mouse strains to *H. felis* has been noted (Sakagami et al., *Am. J. Gastroenterol* 89:1345, 1994).

By histologic assessment, all unimmunized Balb/c mice had 4+ infections ( $> 100$  bacteria/section), whereas reduced bacterial scores were seen in 43% of immunized mice at four weeks. At ten weeks, four of six had reduced urease activity, although only one of six had a reduced bacterial score.

#### The role of antibodies in *Helicobacter* therapy

The role of anti-urease antibodies in *Helicobacter* therapy, i.e., the clearance of *H. felis* from infected mice, was examined by first infecting Balb/c mice with  $10^7$  *H. felis*. Four weeks after infection, the mice were orally immunized with 200  $\mu$ g recombinant urease plus 10  $\mu$ g CT. Control mice were given 10  $\mu$ g CT only. Antigen was administered 4 times at one week intervals. Animals were sacrificed 4 and 10 weeks after the last immunization, and serum and fecal samples were collected for ELISA.

Mice infected with *H. felis* produced serum anti-urease IgG antibodies, but no secretory anti-urease IgA response was detected. However, infected animals immunized with urease/CT exhibited high secretory anti-urease IgA antibody responses (Fig. 13). There was no significant difference in urease specific mucosal IgA levels between immunized mice that remained infected and those with reduced bacterial scores.

These data indicate that *H. felis* infection does not elicit a secretory anti-urease response. Thus, suppression of the IgA antibody response may play a role

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in the ability of *H. felis* to evade clearance by the immune system. In contrast, immunization of *H. felis*-infected mice with urease and a mucosal adjuvant resulted in strong mucosal anti-urease responses, which correlated with clearance of the *H. felis* infection.

Correlation of protection against *Helicobacter* infection with gastric immune responses

Several of the experiments using the mouse infection model showed that some animals rendered resistant to infection by recombinant urease vaccine lacked detectable antibody responses, or had low antibody levels, in serum, saliva, or feces. Thus, the immune response was measured in the gastric mucosa itself, in order to determine whether measurement of an immune response could be more precisely correlated with protection.

Immune responses in gastric mucosa were assessed by detecting IgA antibodies and IgA-positive antibody secreting cells in intestinal and gastric murine tissue by immunohistochemistry. Portions of the stomach containing pylorus-proximal duodenum, antrum, corpus, and cardia were mounted in OCT compound, flash-frozen, and cryosectioned. Sections (7  $\mu$ m thick) were fixed in cold acetone, and IgA-positive cells were identified by staining with biotinylated monoclonal anti-IgA, followed by avidin conjugated to biotinylated glucose oxidase (ABC-GO, Vector Laboratories, Burlingame, CA), and counterstained with methyl green. Urease-specific antibody secreting cells (ASC) were identified by sequentially incubating sections with recombinant urease, rabbit anti-urease, biotinylated donkey anti-rabbit Ig (Amersham, Arlington Heights, IL), ABC-GO, TNBT, and methyl green. Control sections were incubated without urease or urease plus rabbit anti-urease to determine

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reactivity with the donkey secondary reagent and background endogenous glucose oxidase activity.

Cryosections of cell pellets from a hybridoma which produces a monoclonal IgA antibody against *H. felis* ureB (MAB71) and an irrelevant IgA monoclonal (HMK20) against F glycoprotein of respiratory syncytial virus served as positive and negative controls, respectively.

Swiss-Webster mice were immunized orally with four weekly doses of 100 µg recombinant urease plus adjuvant (CT). Control mice received adjuvant only. Groups of three mice each were necropsied at 3, 7, 14, or 21 days after the last immunization. Peyer's patches were removed from the intestines and lamina propria lymphocytes (LPL) were isolated by separation on a 40-70% Percoll gradient. IgA-positive B cells were detected by ELISPOT assays in 96-well filter plates coated with 1 µg/well recombinant urease and blocked with bovine serum albumin. Ten-fold serial dilutions of LPL were added to the wells, starting at  $1 \times 10^6$  cells. IgA-positive ASC were detected with a biotinylated anti-mouse IgA reagent followed by streptavidin-alkaline phosphatase, and positive cells were counted by microscopy.

Anti-urease IgA-positive ASC were found by ELISPOT in intestinal lamina propria as early as three days after the last immunization, peaked at seven days, and diminished thereafter (Table 8). Urease-specific ASC represented ~10% of the total IgA-positive cells observed on immunohistochemistry. Two-color immunofluorescence microscopy confirmed that urease-specific ASC were also IgA-positive. These observations confirm that an intense anti-urease IgA response occurs at the level of the intestinal mucosa after oral antigenic stimulation. The chronology and kinetics of this response are similar to those described for other oral vaccines

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(Czerkinsky et al., *Infect. Immun.* 59:996-1001, 1991; McGhee and Kyono, *Infect. Agents Hum. Dis.* 2:55-73, 1993).

Table 8

5 Kinetics of induction of anti-urease IgA secreting cells  
after oral immunization with recombinant urease

IMMUNIZATION	NUMBER OF ASC/10 <sup>6</sup> LAMINA PROPRIA LYMPHOCYTES			
	DAY 3 <sup>a</sup>	DAY 7	DAY 14	DAY 21
recombinant urease + CT <sup>b</sup>	17 <sup>c</sup>	7400	10	2
10 PBS + CT	1	200	0	0

<sup>a</sup> Day after the last oral immunization.

<sup>b</sup> Cholera toxin.

<sup>c</sup> Average value from duplicate wells containing intestinal lymphocytes from three separate mice.

- 15 To determine whether IgA-positive cells are recruited into the gastric mucosa, stomachs of orally immunized mice were examined by immunohistochemistry, as is described above. IgA-positive cells were virtually absent in gastric mucosa of immunized only and control
- 20 mice, indicating that the stomach is immunologically "silent" until stimulated by *Helicobacter* challenge.

The role of the stomach as an immunological effector organ in challenged, immunized mice was examined. Mice were given four weekly oral doses of

25 200 µg recombinant urease with 10 µg CT. Control mice received CT only. One week after immunization, the mice were challenged. Mice were necropsied prior to challenge and at 7, 14, 28, 70, and 133 days after challenge.

Prior to challenge, no IgA-positive ASC were

30 found. At all time intervals after challenge, IgA-positive ASC were present in large numbers in the gastric

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mucosae of immunized mice, with a peak at seven days (Fig. 14). The number of IgA-positive ASC greatly exceeded that in unimmunized (CT only) mice, especially 7-28 days after challenge. The anatomical localization of IgA-positive ASC also differed, with immunized mice having cells throughout the mucosa, in the lamina propria, and around the crypts, but rarely under the surface epithelium. Urease-specific and IgA-positive ASC revealed that the majority of urease-specific cells in gastric mucosa were IgA-positive.

These observations indicate that the gastric mucosa of animals primed by prior immunization becomes immunologically activated only after antigenic stimulation by *H. felis*. The resulting tissue response is characterized by rapid, intense, and long-lasting recruitment of IgA-positive B cells, many of which are urease specific. This response is quantitatively greater than in immunologically naive mice after challenge. Moreover, the localization of IgA-positive cells in immunized mice differs from that in immunologically naive mice that are challenged and become persistently infected with *H. felis*. The enhanced IgA-positive ASC response in gastric mucosa suggests a basis for the protection conferred by immunization against *H. felis* challenge. These data are concordant with studies of cholera vaccine, in which immunological memory responses triggered within hours after bacterial challenge were sufficient to provide protection (Lycke and Holmgren, *Scand. J. Immunol.* 25:407-412, 1987).

### Correlation of the gastric immune response and bacterial load

The relationship between the gastric tissue immune response and bacterial infection was defined at the structural level. Swiss-Webster mice were immunized with

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4 weekly doses of 200  $\mu$ g recombinant urease with 10  $\mu$ g CT. One week after the last immunization, the mice were challenged with  $10^7$  *H. felis*. Animals were sacrificed 0, 1, 7, 14, 28, 70, and 133 days after challenge, and  
5 *H. felis* colonization was assessed by light and electron microscopy.

Within 24 hours after challenge, both immunized and unimmunized mice had substantial numbers of *H. felis* within the lumen of gastric pits (Fig. 15). Within seven  
10 days after challenge, the bacteria were cleared from the immunized mice, but were still present in high numbers in the gastric pits and the lumens of unimmunized mice. Bacteria were also associated with the apical membrane of mucus-secreting cells of the unimmunized mice. The  
15 clearance of bacteria from the gastric mucosa of immunized mice corresponded to the appearance of IgA-positive ASC and anti-urease ASC in the gastric tissue.

These results suggest the following sequence of events: 1) challenge of immunized mice results in  
20 transient colonization of gastric epithelium with *H. felis*; 2) unimmunized animals remain infected, while animals immunized with recombinant urease clear the bacteria from the stomach during the first week after challenge; and 3) clearance of infection is associated  
25 with the recruitment of IgA-positive urease-specific ASC to gastric mucosa. A similar mechanism may be responsible for the clearance of bacteria from the gastric mucosa of chronically infected animals that are subjected to therapeutic immunization.

30 Antigenic conservation of urease among strains of *H. pylori*

The ability of various antisera to bind multiple clinical isolates of *H. pylori* was tested. The antisera included MPA3, a hyperimmune rabbit serum prepared



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against purified *H. pylori* urease, and sera and secretions (gastric wick samples and saliva) from mice immunized with recombinant urease. Antibody preparations were tested by immunoblotting for recognition of the homologous *H. pylori* strain (Hp630), ATCC 43504 type strain, and five clinical isolates from ulcer patients at St. Bartholomew's Hospital, London, collected within the last five years.

All antisera recognized the UreA and UreB subunits of all *H. pylori* strains, as well as purified native and recombinant *H. pylori* ureases, native and recombinant *H. felis* urease, and native *H. mustelae* urease. In addition, urease-specific IgA antibodies in gastric secretions and saliva of immunized mice reacted with both UreA and UreB of all *H. pylori* strains, as well as heterologous ureases. Immunologic recognition was greater for UreB than for UreA. Sham-immunized mice showed no reactivity with any urease subunits. These results demonstrate that *H. pylori* strains express ureases that are highly conserved at the antigenic level. Thus, antigenic variation among *H. pylori* strains is not a significant factor for development of a recombinant urease vaccine.

#### Combination methods and compositions for treating *Helicobacter* infection

Gastroduodenal infections, such as *Helicobacter* infection, may be treated by oral administration of a vaccine antigen (e.g., *H. pylori* urease) and a mucosal adjuvant, in combination with an antibiotic, an antisecretory agent, a bismuth salt, an antacid, sucralfate, or a combination thereof. Examples of such compounds which may be administered with the vaccine antigen and the adjuvant are: antibiotics, including, e.g., macrolides, tetracyclines,  $\beta$ -lactams,

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aminoglycosides, quinolones, penicillins, and derivatives thereof (specific examples of antibiotics that may be used in the invention include, e.g., amoxicillin, clarithromycin, tetracycline, metronidazole, erythromycin, cefuroxime, and erythromycin); antisecretory agents, including, e.g., H<sub>2</sub>-receptor antagonists (e.g., cimetidine, ranitidine, famotidine, nizatidine, and roxatidine), proton pump inhibitors (e.g., omeprazole, lansoprazole, and pantoprazole), prostaglandin analogs (e.g., misoprostil and enprostil), and anticholinergic agents (e.g., pirenzepine, telenzepine, carbenoxolone, and proglumide); and bismuth salts, including colloidal bismuth subcitrate, tripotassium dicitrate bismuthate, bismuth subsalicylate, bicitropeptide, and pepto-bismol (see, e.g., Goodwin et al., *Helicobacter pylori, Biology and Clinical Practice*, CRC Press, Boca Raton, FL, pp 366-395, 1993; Physicians' Desk Reference, 49<sup>th</sup> edn., Medical Economics Data Production Company, Montvale, New Jersey, 1995). In addition, compounds containing more than one of the above-listed components coupled together, e.g., ranitidine coupled to bismuth subcitrate, may be used.

Amounts of the above-listed compounds used in the methods and compositions of the invention may readily be determined by one skilled in the art. In addition, one skilled the art may readily design treatment/immunization schedules. For example, the non-vaccine components may be administered on days 1-14, and the vaccine antigen + adjuvant may be administered on days 7, 14, 21, and 28.

In addition to urease, other *Helicobacter* antigens may be used in the methods and compositions of the invention involving combination therapy. For example, *Helicobacter* heat shock proteins A or B (HspA or HspB; WO 94/26901), *Helicobacter* adhesion lipoprotein A (AlpA; The nucleotide sequence encoding AlpA is set forth in SEQ ID

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NO:6 and the corresponding amino acid sequence of AlpA is in SEQ ID NO:7), *Helicobacter* (e.g., *H. pylori*) clpB (clpB is encoded by the insert in the plasmid in bacterial strain XLOLR HP CP6, which was deposited with the National Collections of Industrial & Marine Bacteria in Aberdeen, Scotland, and designated with NCIMB accession number 40748), or the 16-19 kD *Helicobacter* antigen recognized by monoclonal antibody IgG 50 (IgG 50 may be obtained from hybridoma cell line #50-G<sub>6</sub>-B<sub>7</sub>, which was deposited with the ATCC and designated with ATCC accession number HB-11952) may be used. In addition, *Helicobacter* surface-exposed or secreted antigens identified using the transposon shuttle mutagenesis method of Haas et al. may be used as vaccine antigens in the invention (Haas et al., Gene 130:23-31, 1993; Haas et al., Abstract from the VI<sup>th</sup> Workshop on Gastroduodenal Pathology and *Helicobacter pylori*, Brussels, September 21-25, 1993; Odenbreit et al., Gut, An International Journal of Gastroenterology and Hepatology, Abstract from the VIII<sup>th</sup> International Workshop on Gastro-duodenal Pathology and *Helicobacter pylori*, Edinburgh, Scotland, July 7-9, 1995). In this method, cloned *H. pylori* genes are mutagenized by transposon insertion mutagenesis in *Escherichia coli*. The inactivated genes are reintroduced into *H. pylori* by DNA transformation, and allelic replacement results in the generation of corresponding *H. pylori* mutants. The transposon used in one variation of this method carries *blaM*, which is a 5'-truncated version of the  $\beta$ -lactamase gene. Use of this transposon facilitates tagging of genes encoding leader peptide-containing exported proteins, and thus direct selection of clones containing mutants of exported proteins (e.g., cell surface proteins such as adhesins and cytotoxins, as well as other potential cell surface virulence factors), which are strong candidates for vaccine antigens. In

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addition to *Helicobacter* antigens, antigens from non-*Helicobacter* gastroduodenal pathogens may be used in methods and compositions for preventing and/or treating infection caused by their respective pathogens.

- 5 Polypeptide fragments containing protective and/or therapeutic epitopes of the above-listed antigens may also be used in the invention.

Adjuvants which may be used in the methods and compositions of the invention include mucosal adjuvants,  
10 e.g., the heat-labile enterotoxin of *E. Coli* (LT), a cholera toxin, a *C. difficile* toxin, or derivatives (e.g., fragments, mutants, or toxoids having adjuvant activity), or combinations thereof. For example, a  
15 fragment containing the 794 carboxyl-terminal amino acids of *C. difficile* Toxin A (see, e.g., Dove et al., *supra*, for the sequence of *C. difficile* Toxin A) may be used. The amounts of vaccine antigen and adjuvant which may be used in these compositions and methods of the invention are described above.

- 20 The efficacy of a composition containing a vaccine (*H. pylori* urease + LT), an antibiotic (amoxicillin), and a bismuth salt (pepto-bismol) in the treatment of *Helicobacter* infection is illustrated below.

#### Combination therapy for *Helicobacter* infection of mice

- 25 One month after infection with  $\sim 10^7$  *H. felis*, mice were treated with amoxicillin (1.5 mg/30 g mouse) and/or pepto-bismol (0.2 mg/30 g mouse) once per day for 14 days (days 1-14), and/or a vaccine composition containing  
30 100  $\mu$ g recombinant *H. pylori* urease + 5  $\mu$ g LT on days 7, 14, 21, and 28 (see Table 9 for an illustration of the combinations used). *Helicobacter* infection in these mice was measured by quantitative gastric urease assay (see above) 1 week and 4 weeks after termination of the treatment (day 28). As is illustrated in Table 9, the

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most effective treatment regimen, achieving 100% clearance, involved administration of a vaccine (urease + LT), an antibiotic (amoxicillin), and a bismuth salt (pepto-bismol).

5 Table 9% Mice Cleared of *H. felis* Infection

<u>treatment weeks</u>		<u>1 week</u>	<u>4</u>
	amoxicillin	60%	40%
10	pepto-bismol	0%	0%
	amoxicillin + pepto-bismol	80%	40%
	vaccine	70%	70%
	vaccine + amoxicillin	89%	56%
15	vaccine + pepto-bismol ~70%	~70%	
	vaccine + amoxicillin + pepto-bismol 100%	100%	

(vaccine = urease + adjuvant)

20 Identification of human patients for administration of recombinant *H. pylori* urease vaccine

The recombinant *H. pylori* urease vaccine of the invention may be administered to uninfected individuals as a prophylactic measure or to individuals infected with *Helicobacter* as an antibacterial therapy. Individuals selected for prophylactic administration of recombinant urease include any individual at risk of *Helicobacter* infection as based upon age, geographical location, or the presence of a condition which renders the individual susceptible to *Helicobacter* infection. Individuals at particularly high risk of infection, or who would be most severely affected by infection, include individuals in

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developing countries, infants and children in developing and in developed countries, individuals with naturally or artificially low gastric acid pH, submarine crews, and military personnel.

5           Individuals who may receive the recombinant *H. pylori* urease vaccine as a therapeutic include those individuals with symptoms of gastritis or other gastrointestinal disorders which may be associated with *H. pylori* infection. The clinical symptoms associated  
10 with gastritis, an inflammation of the stomach mucosa, include a broad range of poorly-defined, and generally inadequately treated, symptoms such as indigestion, "heart burn," dyspepsia, and excessive eructation. A general discussion of gastritis appears in Sleisenger and  
15 Fordtran, In Gastrointestinal Disease, 4th Edn., Saunders Publishing Co., Philadelphia, PA, pp. 772-902, 1989.

          Individuals who have a gastrointestinal disorder may also be treated by administration of the vaccine of the invention. Gastrointestinal disorders includes any  
20 disease or other disorder of the gastrointestinal tract of a human or other mammal. Gastrointestinal disorders include, for example, disorders not manifested by the presence of ulcerations in the gastric mucosa (non-ulcerative gastrointestinal disorder), including chronic  
25 or atrophic gastritis, gastroenteritis, non-ulcer dyspepsia, esophageal reflux disease, gastric motility disorders, and peptic ulcer disease (e.g., gastric and duodenal ulcers). Peptic ulcers involve ulceration and formation of lesions of the mucous membrane of the  
30 esophagus, stomach, or duodenum, and is generally characterized by loss of tissue due to the action of digestive acids, pepsin, or other factors. Alternatively, it may be desirable to administer the vaccine to asymptomatic individuals, particularly where  
35 the individual may have been exposed to *H. pylori* or has

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a condition rendering the individual susceptible to infection.

Infection with *Helicobacter* can be readily diagnosed by a variety of methods well known in the art, including, e.g., by serology, <sup>13</sup>C breath test, and/or gastroscopic examination.

Preparation of purified recombinant urease for administration to patients

The process for formulation of recombinant urease involves combining urease with a stabilizer, (e.g., a carbohydrate mannitol) and freeze drying (i.e., lyophilizing) the product. This process prevents degradation by aggregation and fragmentation. In addition, the product is stable for months following lyophilization. The process which leads to instability involves formation of disulfide bonds between protein subunits, and is effectively inhibited by lyophilization.

Recombinant urease is freeze-dried following the final purification step. The purified protein product (approximately 4 mg/ml) is dialyzed against 2% sucrose, and this solution is transferred to lyophilization vials. The vialled solution is either: (1) frozen in liquid nitrogen, and then placed into the lyophilizer, or (2) cooled to 4°C, and then placed in the lyophilizer, where it is frozen to -40°C, or lower. Lyophilization is carried out using standard methods. The freeze-dried product may be reconstituted in water.

Mode of administration to human patients

Recombinant *H. pylori* urease is administered to a mucosal surface of the individual in order to stimulate a mucosal immune response effective to provide protection to subsequent exposure to *Helicobacter* and/or facilitate

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clearance of a pre-existing *Helicobacter* infection. Preferably, recombinant urease is administered so as to elicit a mucosal immune response associated with production of anti-urease IgA antibodies and/or

5 infiltration of lymphocytes into the gastric mucosa. The recombinant urease may be administered to any mucosal surface of the patient. Preferable mucosal surfaces are intranasal, oral, and rectal (e.g., by use of an anal suppository). In addition to being administered to a

10 single mucosal surface, the vaccine of the invention may be administered to combinations of mucosal surfaces (e.g., oral+rectal, oral+intranasal, or rectal+intranasal). In the case of oral administration, it is preferable that the administration involves

15 ingestion of the vaccine, but the vaccine may also be administered as a mouth wash, so that an immune response is stimulated in the mucosal surface of the oral cavity, without actual ingestion of the vaccine. Alternatively, a systemic mucosal immune response may be achieved by

20 administration of the vaccine to a mucosal surface of the eye in the form of, e.g., an eye drop or an intraocular implant.

Dosages of recombinant *H. pylori* urease administered to the individual as either a prophylactic

25 therapy or an antibacterial therapy can be determined by one skilled in the art. Generally, dosages will contain between about 10  $\mu$ g to 1,000 mg, for example, between about 10 mg and 500 mg, 30 mg and 120 mg, 40 mg and 70 mg, or 60 mg recombinant *H. pylori* urease.

30 At least one dose of the recombinant *H. pylori* urease will be administered to the patient, for example, at least two doses, at least four doses, or with up to six or more total doses administered. It may be desirable to administer booster doses of the recombinant

35 urease at one or two week intervals after the last



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immunization, generally one booster dose containing less than, or the same amount of, recombinant *H. pylori* urease as the initial dose administered. For example, the vaccine regimen may be administered in four doses at one week intervals. The priming and booster doses may be administered to the same or different mucosal surfaces. In the case of different mucosal surfaces, for example, an oral priming dose may be followed by intranasal or rectal boosters, an intranasal priming dose may be followed by oral or rectal boosters, or a rectal priming dose may be followed by oral or intranasal boosters.

Recombinant *H. pylori* urease may be co-administered with a mucosal adjuvant. The mucosal adjuvant may be any mucosal adjuvant known in the art which is appropriate for human use. For example, the mucosal adjuvant may be cholera toxin (CT), enterotoxigenic *E. coli* heat-labile toxin (LT), or a derivative, subunit, or fragment of CT or LT which retains adjuvanticity. The mucosal adjuvant is co-administered with recombinant *H. pylori* urease in an amount effective to elicit or enhance a mucosal immune response, particularly a humoral and/or a mucosal immune response. The ratio of adjuvant to recombinant urease may be determined by standard methods by one skilled in the art. For example, the adjuvant may be present at a ratio of 1 part adjuvant to 10 parts recombinant urease.

A buffer may be administered prior to administration of recombinant *H. pylori* urease in order to neutralize or increase the pH of the gastric acid. Any buffer that is effective in raising the pH of gastric acid and is appropriate for human use may be used. For example, buffers such as sodium bicarbonate, potassium bicarbonate, and sodium phosphate may be used. In the case of oral administration, the vaccine may be buffer-

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free, i.e., no amount of a pH-raising buffer compound effective to significantly affect gastric acid pH is administered to the patient either prior to, or concomitant with, administration of the vaccine

5 recombinant urease.

The vaccine formulation containing recombinant urease may contain a variety of other components, including stabilizers, flavor enhancers (e.g., sugar), or, where the vaccine is administered as an antibacterial

10 therapeutic, other compounds effective in facilitating clearance and/or eradication of the infecting bacteria.

For prophylactic therapy, the vaccine containing recombinant *H. pylori* urease may be administered at any time prior to contact with, or establishment of,

15 *Helicobacter* infection. Because the vaccine can also act as an antibacterial therapy, there is no contraindication for administration of the vaccine if there is marginal evidence or suspicion of a pre-existing *Helicobacter* infection (e.g., an asymptomatic infection).

For use of the vaccine as an antibacterial

20 therapy, recombinant *H. pylori* urease may be administered at any time before, during, or after the onset of symptoms associated with *Helicobacter* infection or with gastritis, peptic ulcers or other gastrointestinal

25 disorder. Although it is not a prerequisite to the initiation of therapy, one may confirm diagnosis of *Helicobacter* infection by, e.g., a  $^{13}\text{C}$  breath test, serology, gastroscopy, biopsy, or another *Helicobacter* detection method known in the art. The progress of

30 immunized patients may be followed by general medical evaluation, screening for *H. pylori* infection by serology,  $^{13}\text{C}$  breath test, and/or gastroscopic examination.

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Example of administration of recombinant *H. pylori* urease to a human

A vaccine composed of 60 mg of recombinant *H. pylori* urease in a total volume of 15 ml of water containing 2% weight/volume sucrose, pH 7.5 is orally administered to the patient. Administration of the vaccine is repeated at weekly intervals for a total of 4 doses. Symptoms are recorded daily by the patient. To determine adverse effects, physician interviews are performed weekly during the period of vaccine administration, as well as 1 week and 1 month after the last immunization. Anti-urease antibodies are measured in serum and saliva, and antibody-secreting cells are monitored in peripheral blood collected 7 days after the last immunization.

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## SEQUENCE LISTING

## (1) GENERAL INFORMATION:

- (i) APPLICANT: OraVax, Inc.
- (ii) TITLE OF INVENTION: MULTIMERIC, RECOMBINANT UREASE VACCINE
- (iii) NUMBER OF SEQUENCES: 7
- (iv) CORRESPONDENCE ADDRESS:
  - (A) ADDRESSEE: Fish & Richardson P.C.
  - (B) STREET: 225 Franklin Street
  - (C) CITY: Boston
  - (D) STATE: MA
  - (E) COUNTRY: USA
  - (F) ZIP: 02110-2804
- (v) COMPUTER READABLE FORM:
  - (A) MEDIUM TYPE: Floppy disk
  - (B) COMPUTER: IBM PC compatible
  - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
  - (D) SOFTWARE: PatentIn Release #1.0, Version #1.25
- (vi) CURRENT APPLICATION DATA:
  - (A) APPLICATION NUMBER: PCT/US96/-----
  - (B) FILING DATE: 23-APR-1996
  - (C) CLASSIFICATION:
- (vii) PRIOR APPLICATION DATA:
  - (A) APPLICATION NUMBER: 08/431,041
  - (B) FILING DATE: 28-APR-1995
  - (C) CLASSIFICATION
- (viii) PRIOR APPLICATION DATA:
  - (A) APPLICATION NUMBER: 08/568,122
  - (B) FILING DATE: 06-DEC-1995
  - (C) CLASSIFICATION
- (ix) ATTORNEY/AGENT INFORMATION:
  - (A) NAME: Clark, Paul T.
  - (B) REGISTRATION NUMBER: 30,162
  - (C) REFERENCE/DOCKET NUMBER: 06132/020001
- (x) TELECOMMUNICATION INFORMATION:
  - (A) TELEPHONE: (617) 542-5070
  - (B) TELEFAX: (617) 542-8906

## (2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 2735 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: double
  - (D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: cDNA
- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

TAATACGACT CACTATAGGG GAATTGTGAG CGGATAACAA TTCATCCACC TTGATTGCGT 60  
TATGTCTTCA AGGAAAAACA CTTTAAGAAT AGGAGAATGA GATGAAACTC ACCCCAAAAG 120

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AGTTAGATAA GTTGATGCTC CACTACGCTG GAGAATTGGC TAAAAACGC AAAGAAAAAG	180
GCATTAAGCT TAACTATGTA GAAGCAGTAG CTTTGATTAG TGCCCATATT ATGGAAGAAG	240
CGAGAGCTGG TAAAAAGACT GCGGCTGAAT TGATGCAAGA AGGGCGCACT CTTTTAAAC	300
CAGATGATGT GATGGATGGC GTGGCAAGCA TGATCCATGA AGTGGGTATT GAAGCGATGT	360
TTCCTGATGG GACTAAACTC GTAACCGTGC ATACCCCTAT TGAGGCCAAT GGTAATTAG	420
TTCCTGGTGA GTTGTCTTA AAAAATGAAG ACATCACTAT CAACGAAGGC AAAAAAGCCG	480
TTAGCGTGAA AGTTAAAAAT GTTGGCGACA GACCGGTTCA AATCGGCTCA CACTTCCATT	540
TCTTTGAAGT GAATAGATGC CTAGACTTTG ACAGAGAAAA AACTTTCGGT AAACGCTTAG	600
ACATTGCGAG CGGGACAGCG GTAAGATTTG AGCCTGGCGA AGAAAAATCC GTAGAATTGA	660
TTGACATTGG CGGTAACAGA AGAATCTTTG GATTTAACGC ATTGGTTGAT AGACAAGCAG	720
ACAACGAAAG CAAAAAATT GCTTTACACA GAGCTAAAGA GCGTGGTTTT CATGGCGCTA	780
AAAGCGATGA CAACTATGTA AAAACAATTA AGGAGTAAGA AATGAAAAAG ATTAGCAGAA	840
AAGAATATGT TTCTATGTAT GGTCTACTA CAGGCGATAA AGTGAGATTG GCGGATACAG	900
ACTTGATCGC TGAAGTAGAA CATGACTACA CCATTTATGG CGAAGAGCTT AAATTCGGTG	960
GCGGTAAAC CCTAAGAGAA GGCATGAGCC AATCTAACAA CCCTAGCAAA GAAGAGTTGG	1020
ATTTAATTAT CACTAACGCT TTAATCGTGG ATTACACCGG TATTATATAA GCGGATATTG	1080
GTATTAAAGA TGGCAAATC GCTGGCATTG GTAAAGGCGG TAACAAAGAC ATGCAAGATG	1140
GCGTTAAAA CAATCTTAGC GTAGGTCCTG CTACTGAAGC CTTAGCCGGT GAAGGTTTGA	1200
TCGTAACGGC TGGTGGTATT GACACACACA TCCACTTCAT TTCACCCCAA CAAATCCCTA	1260
CAGCTTTTGC AAGCGGTGTA ACAACCATGA TTGGTGGTGG AACC GGTCCT GCTGATGGCA	1320
CTAATGCGAC TACTATCACT CCAGGCAGAA GAAATTTAAA ATGGATGCTC AGAGCGGCTG	1380
AAGAATATTC TATGAATTA GGTTCCTTGG CTAAGGTAA CGCTTCTAAC GATGCGAGCT	1440
TAGCCGATCA AATTGAAGCC GGTGCGATTG GCTTTAAAT TCACGAAGAC TGGGGCACCA	1500
CTCCTTCTGC AATCAATCAT GCGTTAGATG TTGCGGACAA ATACGATGTG CAAGTCGCTA	1560
TCCACACAGA CACTTTGAAT GAAGCCGGTT GTGTAGAAGA CACTATGGCT GCTATTGCTG	1620
GACGCACTAT GCACACTTTC CACACTGAAG GCGCTGGCGG CGGACACGCT CCTGATATTA	1680
TTAAAGTAGC CGGTGAACAC AACATTCTTC CCGCTTCCAC TAACCCACC ATCCCTTTCA	1740
CCGTGAATAC AGAAGCAGAG CACATGGACA TGCTTATGGT GTGCCACCAC TTGGATAAAA	1800
GCATTAAAGA AGATGTTTCA TTCGCTGATT CAAGGATCCG CCCTCAAACC ATTGCGGCTG	1860
AAGACACTTT GCATGACATG GGGATTTTCT CAATCACCAG TTCTGACTCT CAAGCGATGG	1920
GCCGTGTGGG TGAAGTTATC ACTAGAACTT GGCAAACAGC TGACAAAAAC AAGAAAGAAT	1980
TTGGCCGCTT GAAAGAAGAA AAAGGCGATA ACGACAACCT CAGGATCAAA CGCTACTTGT	2040

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CTAAATACAC CATTAAACCCA GCGATCGCTC ATGGGATTAG CGAGTATGTA GGTTCAGTAG	2100
AAGTGGGCAA AGTGGCTGAC TTGGTATTGT GGAGTCCAGC ATTCTTTGGC GTGAAACCCA	2160
ACATGATCAT CAAAGGCGGA TTCATTGCGT TAAGCCAAAT GGGCGATGCG AACGCTTCTA	2220
TCCCTACCCC ACAACCGGTT TATTACAGAG AAATGTTCCG TCATCATGGT AAAGCTAAAT	2280
ACGATGCAAA CATCACTTTT GTGTCTCAAG CGGCTTATGA CAAAGGCATT AAAGAAGAAT	2340
TAGGACTTGA AAGACAAGTG TTGCCGGTAA AAAATTGCAG AAATATCACT AAAAAAGACA	2400
TGCAATTCAA CGACACTACT GCTCACATTG AAGTCAATCC TGAAACTTAC CATGTGTTCTG	2460
TGGATGGCAA AGAAGTAACT TCTAAACCAG CCAATAAAGT GAGCTTGGCG CAACTCTTTA	2520
GCATTTTCTA GGATTTTCTA GGAGCAACGC TTCCTTAAAT CCTGAATTCTG AGCTCCGTCG	2580
ACAAGCTTGC GGCCGCACTC GAGCACCACC ACCACCACCA CTGAGATCCG GCTGCTAACA	2640
AAGCCCGAAA GGAAGCTGAG TTGGCTGCTG CCACCGCTGA GCAATAACTA GCATAACCCC	2700
TTGGGGCCTC TAAACGGGTC TTGAGGGGTT TTTTG	2735

## (2) INFORMATION FOR SEQ ID NO:2:

- (i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 238 amino acids  
 (B) TYPE: amino acid  
 (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met	Lys	Leu	Thr	Pro	Lys	Glu	Leu	Asp	Lys	Leu	Met	Leu	His	Tyr	Ala
1				5					10					15	
Gly	Glu	Leu	Ala	Lys	Lys	Arg	Lys	Glu	Lys	Gly	Ile	Lys	Leu	Asn	Tyr
			20					25					30		
Val	Glu	Ala	Val	Ala	Leu	Ile	Ser	Ala	His	Ile	Met	Glu	Glu	Ala	Arg
		35					40					45			
Ala	Gly	Lys	Lys	Thr	Ala	Ala	Glu	Leu	Met	Gln	Glu	Gly	Arg	Thr	Leu
	50				55					60					
Leu	Lys	Pro	Asp	Asp	Val	Met	Asp	Gly	Val	Ala	Ser	Met	Ile	His	Glu
	65				70				75					80	
Val	Gly	Ile	Glu	Ala	Met	Phe	Pro	Asp	Gly	Thr	Lys	Leu	Val	Thr	Val
			85					90					95		
His	Thr	Pro	Ile	Glu	Ala	Asn	Gly	Lys	Leu	Val	Pro	Gly	Glu	Leu	Phe
		100					105					110			
Leu	Lys	Asn	Glu	Asp	Ile	Thr	Ile	Asn	Glu	Gly	Lys	Lys	Ala	Val	Ser
		115					120					125			
Val	Lys	Val	Lys	Asn	Val	Gly	Asp	Arg	Pro	Val	Gln	Ile	Gly	Ser	His
	130					135					140				

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Phe His Phe Phe Glu Val Asn Arg Cys Leu Asp Phe Asp Arg Glu Lys  
 145 150 155 160  
 Thr Phe Gly Lys Arg Leu Asp Ile Ala Ser Gly Thr Ala Val Arg Phe  
 165 170 175  
 Glu Pro Gly Glu Glu Lys Ser Val Glu Leu Ile Asp Ile Gly Gly Asn  
 180 185 190  
 Arg Arg Ile Phe Gly Phe Asn Ala Leu Val Asp Arg Gln Ala Asp Asn  
 195 200 205  
 Glu Ser Lys Lys Ile Ala Leu His Arg Ala Lys Glu Arg Gly Phe His  
 210 215 220  
 Gly Ala Lys Ser Asp Asp Asn Tyr Val Lys Thr Ile Lys Glu  
 225 230 235

## (2) INFORMATION FOR SEQ ID NO:3:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 566 amino acids
  - (B) TYPE: amino acid
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Met Lys Lys Ile Ser Arg Lys Glu Tyr Val Ser Met Tyr Gly Pro Thr  
 1 5 10 15  
 Thr Gly Asp Lys Val Arg Leu Gly Asp Thr Asp Leu Ile Ala Glu Val  
 20 25 30  
 Glu His Asp Tyr Thr Ile Tyr Gly Glu Glu Leu Lys Phe Gly Gly Gly  
 35 40 45  
 Lys Thr Leu Arg Glu Gly Met Ser Gln Ser Asn Asn Pro Ser Lys Glu  
 50 55 60  
 Glu Leu Asp Leu Ile Ile Thr Asn Ala Leu Ile Val Asp Tyr Thr Gly  
 65 70 75 80  
 Ile Tyr Lys Ala Asp Ile Gly Ile Lys Asp Gly Lys Ile Ala Gly Ile  
 85 90 95  
 Gly Lys Gly Gly Asn Lys Asp Met Gln Asp Gly Val Lys Asn Asn Leu  
 100 105 110  
 Ser Val Gly Pro Ala Thr Glu Ala Leu Ala Gly Glu Gly Leu Ile Val  
 115 120 125  
 Thr Ala Gly Gly Ile Asp Thr His Ile His Phe Ile Ser Pro Gln Gln  
 130 135 140  
 Ile Pro Thr Ala Phe Ala Ser Gly Val Thr Thr Met Ile Gly Gly Gly  
 145 150 155 160  
 Thr Gly Pro Ala Asp Gly Thr Asn Ala Thr Thr Ile Thr Pro Gly Arg  
 165 170 175

- 72 -

Arg Asn Leu Lys Trp Met Leu Arg Ala Ala Glu Glu Tyr Ser Met Asn  
 180 185 190  
 Leu Gly Phe Leu Ala Lys Gly Asn Ala Ser Asn Asp Ala Ser Leu Ala  
 195 200 205  
 Asp Gln Ile Glu Ala Gly Ala Ile Gly Phe Lys Ile His Glu Asp Trp  
 210 215 220  
 Gly Thr Thr Pro Ser Ala Ile Asn His Ala Leu Asp Val Ala Asp Lys  
 225 230 235 240  
 Tyr Asp Val Gln Val Ala Ile His Thr Asp Thr Leu Asn Glu Ala Gly  
 245 250 255  
 Cys Val Glu Asp Thr Met Ala Ala Ile Ala Gly Arg Thr Met His Thr  
 260 265 270  
 Phe His Thr Glu Gly Ala Gly Gly Gly His Ala Pro Asp Ile Ile Lys  
 275 280 285  
 Val Ala Gly Glu His Asn Ile Leu Pro Ala Ser Thr Asn Pro Thr Ile  
 290 295 300  
 Pro Phe Thr Val Asn Thr Glu Ala Glu His Met Asp Met Leu Met Val  
 305 310 315 320  
 Cys His His Leu Asp Lys Ser Ile Lys Glu Asp Val Gln Phe Ala Asp  
 325 330 335  
 Ser Arg Ile Arg Pro Gln Thr Ile Ala Ala Glu Asp Thr Leu His Asp  
 340 345 350  
 Met Gly Ile Phe Ser Ile Thr Ser Ser Asp Ser Gln Ala Met Gly Arg  
 355 360 365  
 Val Gly Glu Val Ile Thr Arg Thr Trp Gln Thr Ala Asp Lys Asn Lys  
 370 375 380  
 Lys Glu Phe Gly Arg Leu Lys Glu Glu Lys Gly Asp Asn Asp Asn Phe  
 385 390 395 400  
 Arg Ile Lys Arg Tyr Leu Ser Lys Tyr Thr Ile Asn Pro Ala Ile Ala  
 405 410 415  
 His Gly Ile Ser Glu Tyr Val Gly Ser Val Glu Val Gly Lys Val Ala  
 420 425 430  
 Asp Leu Val Leu Trp Ser Pro Ala Phe Phe Gly Val Lys Pro Asn Met  
 435 440 445  
 Ile Ile Lys Gly Gly Phe Ile Ala Leu Ser Gln Met Gly Asp Ala Asn  
 450 455 460  
 Ala Ser Ile Pro Thr Pro Gln Pro Val Tyr Tyr Arg Glu Met Phe Ala  
 465 470 475 480  
 His His Gly Lys Ala Lys Tyr Asp Ala Asn Ile Thr Phe Val Ser Gln  
 485 490 495  
 Ala Ala Tyr Asp Lys Gly Ile Lys Glu Glu Leu Gly Leu Glu Arg Gln  
 500 505 510



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Val Leu Pro Val Lys Asn Cys Arg Asn Ile Thr Lys Lys Asp Met Gln  
                   515                                  520                                  525

Phe Asn Asp Thr Thr Ala His Ile Glu Val Asn Pro Glu Thr Tyr His  
                   530                                  535                                  540

Val Phe Val Asp Gly Lys Glu Val Thr Ser Lys Pro Ala Asn Lys Val  
                   545                                  550                                  555                                  560

Ser Leu Ala Gln Leu Phe  
                                   565

## (2) INFORMATION FOR SEQ ID NO:4:

- (i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 28 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: both  
 (D) TOPOLOGY: both

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

CGGGATCCAC CTTGATTGCG TTATGTCT

28

## (2) INFORMATION FOR SEQ ID NO:5:

- (i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 27 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: both  
 (D) TOPOLOGY: both

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

CGGAATTCAG GATTTAAGGA AGCGTTG

27

## (2) INFORMATION FOR SEQ ID NO:6:

- (i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 1557 base pairs  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: both  
 (D) TOPOLOGY: both

(ii) MOLECULE TYPE: cDNA

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

ATGATAAAAA AGAATAGAAC GCTGTTTCTT AGTCTAGCCC TTTGCGCTAG CATAAGTTAT 60

GCCGAAGATG ATGGAGGGTT TTTCACCGTC GGTATCAGC TCGGGCAAGT CATGCAAGAT 120

GTCCAAAACC CAGGCGGCGC TAAAGCGAC GAACGCGCA GAGAGCTTAA CGCTGATGTA 180

ACGAACAACA TTTTAAACAA CAACACCGGA GGCAACATCG CAGGGGCGTT GAGTAACGCT 240

TTCTCCCAAT ACCTTTATTC GCTTTTAGGG GCTTACCCCA CAAACTCAA TGGTAGCGAT 300

GTGTCTGCGA ACGCTCTTTT AAGTGGTGCG GTAGGCTCTG GGACTTGTGC GGCTGCAGGG 360

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ACGGCTGGTG GCACTTCTCT TAACACTCAA AGCACTTGCA CCGTTGCGGG CTATTACTGG	420
CTCCCTAGCT TGA CTGACAG GATTTTAAGC ACGATCGGCA GCCAGACTAA CTACGGCAGC	480
AACACCAATT TCCCCAACAT GCAACAACAG CTCACCTACT TGAATGCGGG GAATGTGTTT	540
TTTAATGCGA TGAATAAGGC TTTAGAGAAT AAGAATGGAA CTAGTAGTGC TAGTGGAAC	600
AGTGGTGCGA CTGGTTCAGA TGGTCAAAC TACTCCACAC AAGCTATCCA ATACCTTCAA	660
GGCCAACAAA ATATCTTAAA TAACGCAGCG AACTTGCTCA AGCAAGATGA ATTGCTCTTA	720
GAAGCTTTCA ACTCTGCCGT AGCCGCCAAC ATTGGGAATA AGGAATTCAA TTCAGCCGCT	780
TTTACAGGTT TGGTGCAAGG CATTATTGAT CAATCTCAAG CGGTTTATAA CGAGCTCACT	840
AAAAACACCA TTAGCGGGAG TGCGGTTATT AGCGCTGGGA TAAACTCCA CCAAGCTAAC	900
GCTGTGCAAG GCGCGCTAG TCAGCTCCCT AACGCTCTTT ATAACGCGCA AGTAACTTTG	960
GATAAAATCA ATGCGCTCAA TAATCAAGTG AGAAGCATGC CTTACTTGCC CCAATTCAGA	1020
CGCGGGAACA CGCGTTCAAC GAATATTTTA AACGGGTTTT ACACCAAAT AGGCTATAAG	1080
CAATTCTTCG GGAAGAAAAG GAATATCGGT TTGCGCTATT ATGTTTCTT TTCTTATAAC	1140
GGAGCGAGCG TGGGCTTTAG ATCCACTCAA AATAATGTAG GGTATACAC TTATGGGGTG	1200
GGGACTGATG TGTTGTATAA CATCTTTAGC CGCTCCTATC AAAACCGCTC TGTGGATATG	1260
GGCTTTTTTA GCGGTATCCA ATTAGCCGGT GAGACCTTCC AATCCACGCT CAGAGATGAC	1320
CCCAATGTGA AATTGCATGG GAAAATCAAT AACACGCACT TCCAGTTCCT CTTTGACTTC	1380
GGTATGAGGA TGAACCTCGG TAAGTTGGAC GGGAAATCCA ACCGCCACAA CCAGCACACG	1440
GTGGAATTTG GCGTAGTGGT GCCTACGATT TATAACACTT ATTACAAATC AGCAGGGACT	1500
ACCGTGAAGT ATTTCCGTCC TTATAGCGTT TATTGGTCTT ATGGGTATTC ATTCTAA	1557

## (2) INFORMATION FOR SEQ ID NO:7:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 518 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

Met	Ile	Lys	Lys	Asn	Arg	Thr	Leu	Phe	Leu	Ser	Leu	Ala	Leu	Cys	Ala
1				5					10					15	
Ser	Ile	Ser	Tyr	Ala	Glu	Asp	Asp	Gly	Gly	Phe	Phe	Thr	Val	Gly	Tyr
			20					25					30		
Gln	Leu	Gly	Gln	Val	Met	Gln	Asp	Val	Gln	Asn	Pro	Gly	Gly	Ala	Lys
		35				40					45				
Ser	Asp	Glu	Leu	Ala	Arg	Glu	Leu	Asn	Ala	Asp	Val	Thr	Asn	Asn	Ile
	50					55					60				

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Leu Asn Asn Asn Thr Gly Gly Asn Ile Ala Gly Ala Leu Ser Asn Ala  
 65 70 75 80  
 Phe Ser Gln Tyr Leu Tyr Ser Leu Leu Gly Ala Tyr Pro Thr Lys Leu  
 85 90 95  
 Asn Gly Ser Asp Val Ser Ala Asn Ala Leu Leu Ser Gly Ala Val Gly  
 100 105 110  
 Ser Gly Thr Cys Ala Ala Ala Gly Thr Ala Gly Gly Thr Ser Leu Asn  
 115 120 125  
 Thr Gln Ser Thr Cys Thr Val Ala Gly Tyr Tyr Trp Leu Pro Ser Leu  
 130 135 140  
 Thr Asp Arg Ile Leu Ser Thr Ile Gly Ser Gln Thr Asn Tyr Gly Thr  
 145 150 155 160  
 Asn Thr Asn Phe Pro Asn Met Gln Gln Gln Leu Thr Tyr Leu Asn Ala  
 165 170 175  
 Gly Asn Val Phe Phe Asn Ala Met Asn Lys Ala Leu Glu Asn Lys Asn  
 180 185 190  
 Gly Thr Ser Ser Ala Ser Gly Thr Ser Gly Ala Thr Gly Ser Asp Gly  
 195 200 205  
 Gln Thr Tyr Ser Thr Gln Ala Ile Gln Tyr Leu Gln Gly Gln Gln Asn  
 210 215 220  
 Ile Leu Asn Asn Ala Ala Asn Leu Leu Lys Gln Asp Glu Leu Leu Leu  
 225 230 235 240  
 Glu Ala Phe Asn Ser Ala Val Ala Ala Asn Ile Gly Asn Lys Glu Phe  
 245 250 255  
 Asn Ser Ala Ala Phe Thr Gly Leu Val Gln Gly Ile Ile Asp Gln Ser  
 260 265 270  
 Gln Ala Val Tyr Asn Glu Leu Thr Lys Asn Thr Ile Ser Gly Ser Ala  
 275 280 285  
 Val Ile Ser Ala Gly Ile Asn Ser Asn Gln Ala Asn Ala Val Gln Gly  
 290 295 300  
 Arg Ala Ser Gln Leu Pro Asn Ala Leu Tyr Asn Ala Gln Val Thr Leu  
 305 310 315 320  
 Asp Lys Ile Asn Ala Leu Asn Asn Gln Val Arg Ser Met Pro Tyr Leu  
 325 330 335  
 Pro Gln Phe Arg Ala Gly Asn Ser Arg Ser Thr Asn Ile Leu Asn Gly  
 340 345 350  
 Phe Tyr Thr Lys Ile Gly Tyr Lys Gln Phe Phe Gly Lys Lys Arg Asn  
 355 360 365  
 Ile Gly Leu Arg Tyr Tyr Gly Phe Phe Ser Tyr Asn Gly Ala Ser Val  
 370 375 380  
 Gly Phe Arg Ser Thr Gln Asn Asn Val Gly Leu Tyr Thr Tyr Gly Val  
 385 390 395 400

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Gly Thr Asp Val Leu Tyr Asn Ile Phe Ser Arg Ser Tyr Gln Asn Arg  
 405 410 415  
 Ser Val Asp Met Gly Phe Phe Ser Gly Ile Gln Leu Ala Gly Glu Thr  
 420 425 430  
 Phe Gln Ser Thr Leu Arg Asp Asp Pro Asn Val Lys Leu His Gly Lys  
 435 440 445  
 Ile Asn Asn Thr His Phe Gln Phe Leu Phe Asp Phe Gly Met Arg Met  
 450 455 460  
 Asn Phe Gly Lys Leu Asp Gly Lys Ser Asn Arg His Asn Gln His Thr  
 465 470 475 480  
 Val Glu Phe Gly Val Val Val Pro Thr Ile Tyr Asn Thr Tyr Tyr Lys  
 485 490 495  
 Ser Ala Gly Thr Thr Val Lys Tyr Phe Arg Pro Tyr Ser Val Tyr Trp  
 500 505 510  
 Ser Tyr Gly Tyr Ser Phe  
 515

What is claimed is:

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1. A vaccine for inducing a mucosal immune response to *Helicobacter* in a patient, said vaccine comprising:
  - a) multimeric complexes of recombinant,  
5 enzymatically inactive *Helicobacter* urease; and
  - b) a pharmaceutically acceptable carrier or diluent.
2. The vaccine of claim 1, comprising a multimeric complex comprising eight Urease A subunits and  
10 eight Urease B subunits, a multimeric complex comprising six Urease A subunits and six Urease B subunits, and a multimeric complex comprising four Urease A subunits and four Urease B subunits, or a mixture thereof.
3. The vaccine of claim 1, comprising a  
15 multimeric complex comprising eight Urease A subunits and eight Urease B subunits, a multimeric complex comprising six Urease A subunits and six Urease B subunits, and a multimeric complex comprising four Urease A subunits and four Urease B subunits.
- 20 4. The vaccine of claim 1, further comprising a mucosal adjuvant.
5. The vaccine of claim 1, wherein said mucosal adjuvant is the heat-labile enterotoxin of enterotoxigenic *Escherichia coli*, a cholera toxin, a  
25 *Clostridium difficile* toxin, a subunit or derivative thereof lacking toxicity but still having adjuvant activity, or a mixture thereof.
6. The vaccine of claim 4, wherein said mucosal adjuvant is the heat-labile enterotoxin of  
30 enterotoxigenic *Escherichia coli*, or a subunit or

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derivative thereof lacking toxicity but retaining adjuvant activity.

7. The vaccine of claim 4, wherein said mucosal adjuvant is a cholera toxin, or a subunit or derivative thereof lacking toxicity but retaining adjuvant activity.

8. The vaccine of claim 4, wherein said mucosal adjuvant is a *Clostridium difficile* toxin, or a subunit or derivative thereof lacking toxicity but retaining adjuvant activity.

9. The vaccine of claim 8, wherein said mucosal adjuvant comprises the carbohydrate binding domain of *Clostridium difficile* Toxin A.

10. The vaccine of claim 1, wherein said multimeric complexes of recombinant, enzymatically inactive *Helicobacter urease* have been freeze-dried.

11. The vaccine of claim 1, wherein said *Helicobacter urease* is *Helicobacter pylori urease*.

12. A composition for treating a gastroduodenal infection in a patient, said composition comprising (a) an antigen from a gastroduodenal pathogen, and (b) an antibiotic, an antisecretory agent, a bismuth salt, or a combination thereof.

13. The composition of claim 12, wherein said gastroduodenal pathogen is a *Helicobacter*.

14. The composition of claim 13, wherein said *Helicobacter* is *Helicobacter pylori*.

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15. The composition of claim 13, wherein said antigen is a urease.

16. The composition of claim 13, wherein said antigen comprises multimeric complexes of recombinant,  
5 enzymatically inactive *Helicobacter* urease.

17. The composition of claim 13, comprising a multimeric complex comprising eight Urease A subunits and eight Urease B subunits, a multimeric complex comprising six Urease A subunits and six Urease B subunits, and a  
10 multimeric complex comprising four Urease A subunits and four Urease B subunits, or a mixture thereof.

18. The composition of claim 13, comprising a multimeric complex comprising eight Urease A subunits and eight Urease B subunits, a multimeric complex comprising  
15 six Urease A subunits and six Urease B subunits, and a multimeric complex comprising four Urease A subunits and four Urease B subunits.

19. The composition of claim 12, wherein said *Helicobacter* infection is *Helicobacter pylori* infection.

20. The composition of claim 12, further comprising a mucosal adjuvant.

21. The composition of claim 20, wherein said mucosal adjuvant is the heat-labile enterotoxin of enterotoxigenic *Escherichia coli*, a cholera toxin, a  
25 *Clostridium difficile* toxin, a subunit or derivative thereof lacking toxicity but still having adjuvant activity, or a mixture thereof.

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22. The composition of claim 20, wherein said mucosal adjuvant is the heat-labile enterotoxin of enterotoxigenic *Escherichia coli*, or a subunit or derivative thereof lacking toxicity but still having adjuvant activity.

23. The composition of claim 20, wherein said mucosal adjuvant is a cholera toxin, or a subunit or derivative thereof lacking toxicity but still having adjuvant activity.

24. The composition of claim 20, wherein said mucosal adjuvant is a *Clostridium difficile* toxin, or a derivative thereof lacking toxicity but still having adjuvant activity.

25. The composition of claim 24, wherein said mucosal adjuvant comprises the carbohydrate binding domain of *Clostridium difficile* Toxin A.

26. The composition of claim 12, wherein said antibiotic is selected from the group consisting of amoxicillin, clarithromycin, tetracycline, metronidazole, and erythromycin.

27. The composition of claim 12, wherein said bismuth salt is selected from the group consisting of bismuth subcitrate and bismuth subsalicylate.

28. The composition of claim 12, wherein said antisecretory agent is a proton pump inhibitor.

29. The composition of claim 28, wherein said proton pump inhibitor is selected from the group consisting of omeprazole, lansoprazole, and pantoprazole.



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30. The composition of claim 12, wherein said antisecretory agent is an H<sub>2</sub>-receptor antagonist.

31. The composition of claim 30, wherein said H<sub>2</sub>-receptor antagonist is selected from the group consisting  
5 of ranitidine, cimetidine, famotidine, nizatidine, and roxatidine.

32. The composition of claim 12, wherein said antisecretory agent is a prostaglandin analog.

33. The composition of claim 32, wherein said  
10 prostaglandin analog is misoprostil or enprostil.



FIG. 1

## Restriction enzyme map of urease PCR product

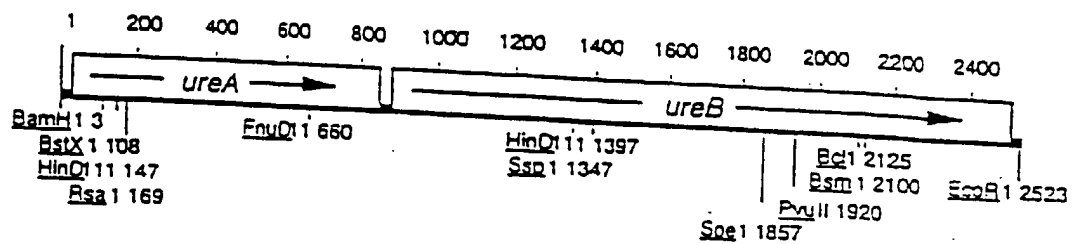
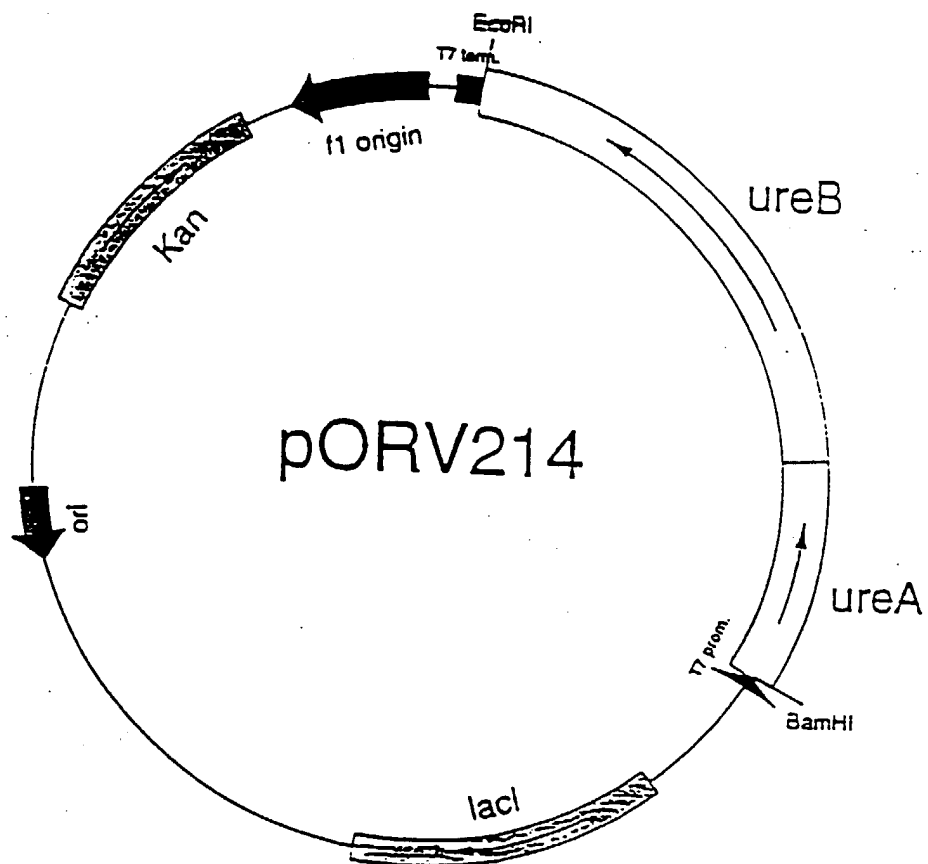




FIG. 2

Genetic map of expression plasmid pORV214





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FIG. 3

Complete nucleotide sequence of *ureA* and *ureB* with regulatory sequences

Diagram illustrating the complete nucleotide sequence of *ureA* and *ureB* with regulatory sequences. The sequences are presented in two columns, with line numbers indicating the position of each nucleotide.

**Left Column (Top):**

111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1043 1044 1045 1046 1047 1048 1049 1050 1051 1052 1053 1054 1055 1056 1057 1058 1059 1060 1061 1062 1063 1064 1065 1066 1067 1068 1069 1070 1071 1072 1073 1074 1075 1076 1077 1078 1079 1080 1081 1082 1083 1084 1085 1086 1087 1088 1089 1090 1091 1092 1093 1094 1095 1096 1097 1098 1099 1100 1101 1102 1103 1104 1105 1106 1107 1108 1109 1110 1111 1112 1113 1114 1115 1116 1117 1118 1119 1120 1121 1122 1123 1124 1125 1126 1127 1128 1129 1130 1131 1132 1133 1134 1135 1136 1137 1138 1139 1140 1141 1142 1143 1144 1145 1146 1147 1148 1149 1150 1151 1152 1153 1154 1155 1156 1157 1158 1159 1160 1161 1162 1163 1164 1165 1166 1167 1168 1169 1170 1171 1172 1173 1174 1175 1176 1177 1178 1179 1180 1181 1182 1183 1184 1185 1186 1187 1188 1189 1190 1191 1192 1193 1194 1195 1196 1197 1198 1199 1200 1201 1202 1203 1204 1205 1206 1207 1208 1209 1210 1211 1212 1213 1214 1215 1216 1217 1218 1219 1220 1221 1222 1223 1224 1225 1226 1227 1228 1229 1230 1231 1232 1233 1234 1235 1236 1237 1238 1239 1240 1241 1242 1243 1244 1245 1246 1247 1248 1249 1250 1251 1252 1253 1254 1255 1256 1257 1258 1259 1260 1261 1262 1263 1264 1265 1266 1267 1268 1269 1270 1271 1272 1273 1274 1275 1276 1277 1278 1279 1280 1281 1282 1283 1284 1285 1286 1287 1288 1289 1290 1291 1292 1293 1294 1295 1296 1297 1298 1299 1300 1301 1302 1303 1304 1305 1306 1307 1308 1309 1310 1311 1312 1313 1314 1315 1316 1317 1318 1319 1320 1321 1322 1323 1324 1325 1326 1327 1328 1329 1330 1331 1332 1333 1334 1335 1336 1337 1338 1339 1340 1341 1342 1343 1344 1345 1346 1347 1348 1349 1350 1351 1352 1353 1354 1355 1356 1357 1358 1359 1360 1361 1362 1363 1364 1365 1366 1367 1368 1369 1370 1371 1372 1373 1374 1375 1376 1377 1378 1379 1380 1381 1382 1383 1384 1385 1386 1387 1388 1389 1390 1391 1392 1393 1394 1395 1396 1397 1398 1399 1400 1401 1402 1403 1404 1405 1406 1407 1408 1409 1410 1411 1412 1413 1414 1415 1416 1417 1418 1419 1420 1421 1422 1423 1424 1425 1426 1427 1428 1429 1430 1431 1432 1433 1434 1435 1436 1437 1438 1439 1440 1441 1442 1443 1444 1445 1446 1447 1448 1449 1450 1451 1452 1453 1454 1455 1456 1457 1458 1459 1460 1461 1462 1463 1464 1465 1466 1467 1468 1469 1470 1471 1472 1473 1474 1475 1476 1477 1478 1479 1480 1481 1482 1483 1484 1485 1486 1487 1488 1489 1490 1491 1492 1493 1494 1495 1496 1497 1498 1499 1500 1501 1502 1503 1504 1505 1506 1507 1508 1509 1510 1511 1512 1513 1514 1515 1516 1517 1518 1519 1520 1521 1522 1523 1524 1525 1526 1527 1528 1529 1530 1531 1532 1533 1534 1535 1536 1537 1538 1539 1540 1541 1542 1543 1544 1545 1546 1547 1548 1549 1550 1551 1552 1553 1554 1555 1556 1557 1558 1559 1560 1561 1562 1563 1564 1565 1566 1567 1568 1569 1570 1571 1572 1573 1574 1575 1576 1577 1578 1579 1580 1581 1582 1583 1584 1585 1586 1587 1588 1589 1590 1591 1592 1593 1594 1595 1596 1597 1598 1599 1600 1601 1602 1603 1604 1605 1606 1607 1608 1609 1610 1611 1612 1613 1614 1615 1616 1617 1618 1619 1620 1621 1622 1623 1624 1625 1626 1627 1628 1629 1630 1631 1632 1633 1634 1635 1636 1637 1638 1639 1640 1641 1642 1643 1644 1645 1646 1647 1648 1649 1650 1651 1652 1653 1654 1655 1656 1657 1658 1659 1660 1661 1662 1663 1664 1665 1666 1667 1668 1669 1670 1671 1672 1673 1674 1675 1676 1677 1678 1679 1680 1681 1682 1683 1684 1685 1686 1687 1688 1689 1690 1691 1692 1693 1694 1695 1696 1697 1698 1699 1700 1701 1702 1703 1704 1705 1706 1707 1708 1709 1710 1711 1712 1713 1714 1715 1716 1717 1718 1719 1720 1721 1722 1723 1724 1725 1726 1727 1728 1729 1730 1731 1732 1733 1734 1735 1736 1737 1738 1739 1740 1741 1742 1743 1744 1745 1746 1747 1748 1749 1750 1751 1752 1753 1754 1755 1756 1757 1758 1759 1760 1761 1762 1763 1764 1765 1766 1767 1768 1769 1770 1771 1772 1773 1774 1775 1776 1777 1778 1779 1780 1781 1782 1783 1784 1785 1786 1787 1788 1789 1790 1791 1792 1793 1794 1795 1796 1797 1798 1799 1800 1801 1802 1803 1804 1805 1806 1807 1808 1809 1810 1811 1812 1813 1814 1815 1816 1817 1818 1819 1820 1821 1822 1823 1824 1825 1826 1827 1828 1829 1830 1831 1832 1833 1834 1835 1836 1837 1838 1839 1840 1841 1842 1843 1844 1845 1846 1847 1848 1849 1850 1851 1852 1853 1854 1855 1856 1857 1858 1859 1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873 1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 2222 2223 2224 2225 2226 2227 2228 2229 2230 2231 2232 2233 2234 2235 2236 2237 2238 2239 2240 2241 2242 2243 2244 2245 2246 2247 2248 2249 2250 2251 2252 2253 2254 2255 2256 2257 2258 2259 2260 2261 2262 2263 2264 2265 2266 2267 2268 2269 2270 2271 2272 2273 2274 2275 2276 2277 2278 2279 2280 2281 2282 2283 2284 2285 2286 2287 2288 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2489 2490 2491 2492 2493 2494 2495 2496 2497 2498 2499 2500 2501 2502 2503 2504 2505 2506 2507 2508 2509 2510 2511 2512 2513 2514 2515 2516 2517 2518 2519 2520 2521 2522 2523 2524 2525 2526 2527 2528 2529 2530 2531 2532 2533 2534 2535 2536 2537 2538 2539 2540 2541 2542 2543 2544 2545 2546 2547 2548 2549 2550 2551 2552 2553 2554 2555 2556 2557 2558 2559 2560 2561 2562 2563 2564 2565 2566 2567 2568 2569 2570 2571 2572 2573 2574 2575 2576 2577 2578 2579 2580 2581 2582 2583 2584 2585 2586 2587 2588 2589 2590 2591 2592 2593 2594 2595 2596 2597 2598 2599 2600 2601 2602 2603 2604 2605 2606 2607 2608 2609 2610 2611 2612 2613 2614 2615 2616 2617 2618 2619 2620 2621 2622 2623 2624 2625 2626 2627 2628 2629 2630 2631 2632 2633 2634 2635 2636 2637 2638 2639 2640 2641 2642 2643 2644 2645 2646 2647 2648 2649 2650 2651 2652 2653 2654 2655 2656 2657 2658 2659 2660 2661 2662 2663 2664 2665 2666 2667 2668 2669 2670 2671 2672 2673 2674 2675 2676 2677 2678 2679 2680 2681 2682 2683 2684 2685 2686 2687 2688 2689 2690 2691 2692 2693 2694 2695 2696 2697 2698 2699 2700 2701 2702 2703 2704 2705 270





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FIG. 4

Analytical size-exclusion HPLC profile of purified recombinant urease

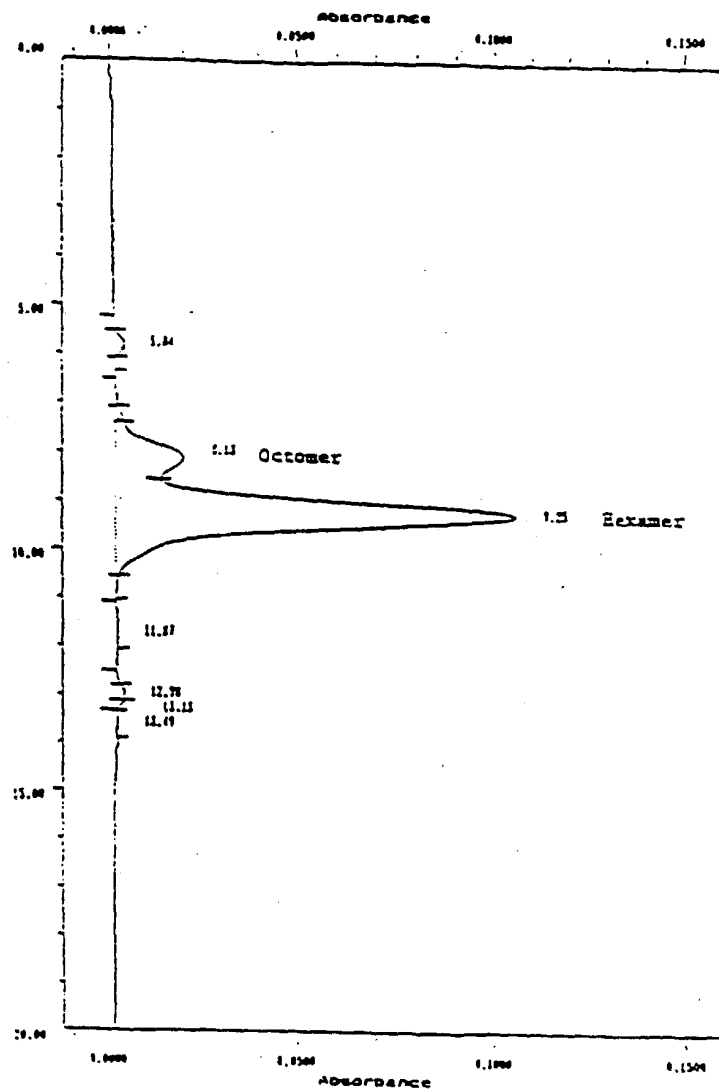


FIG. 5

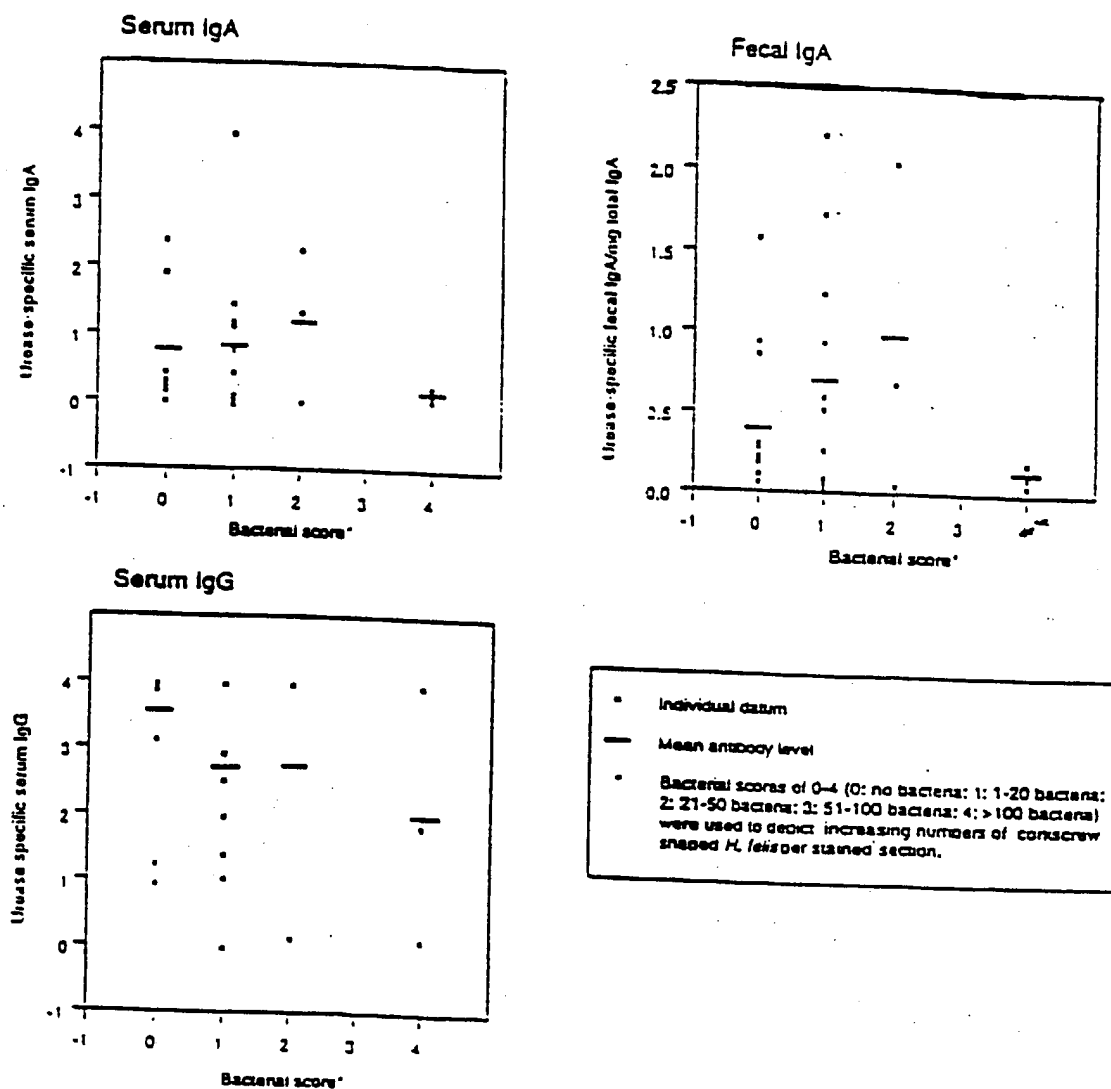
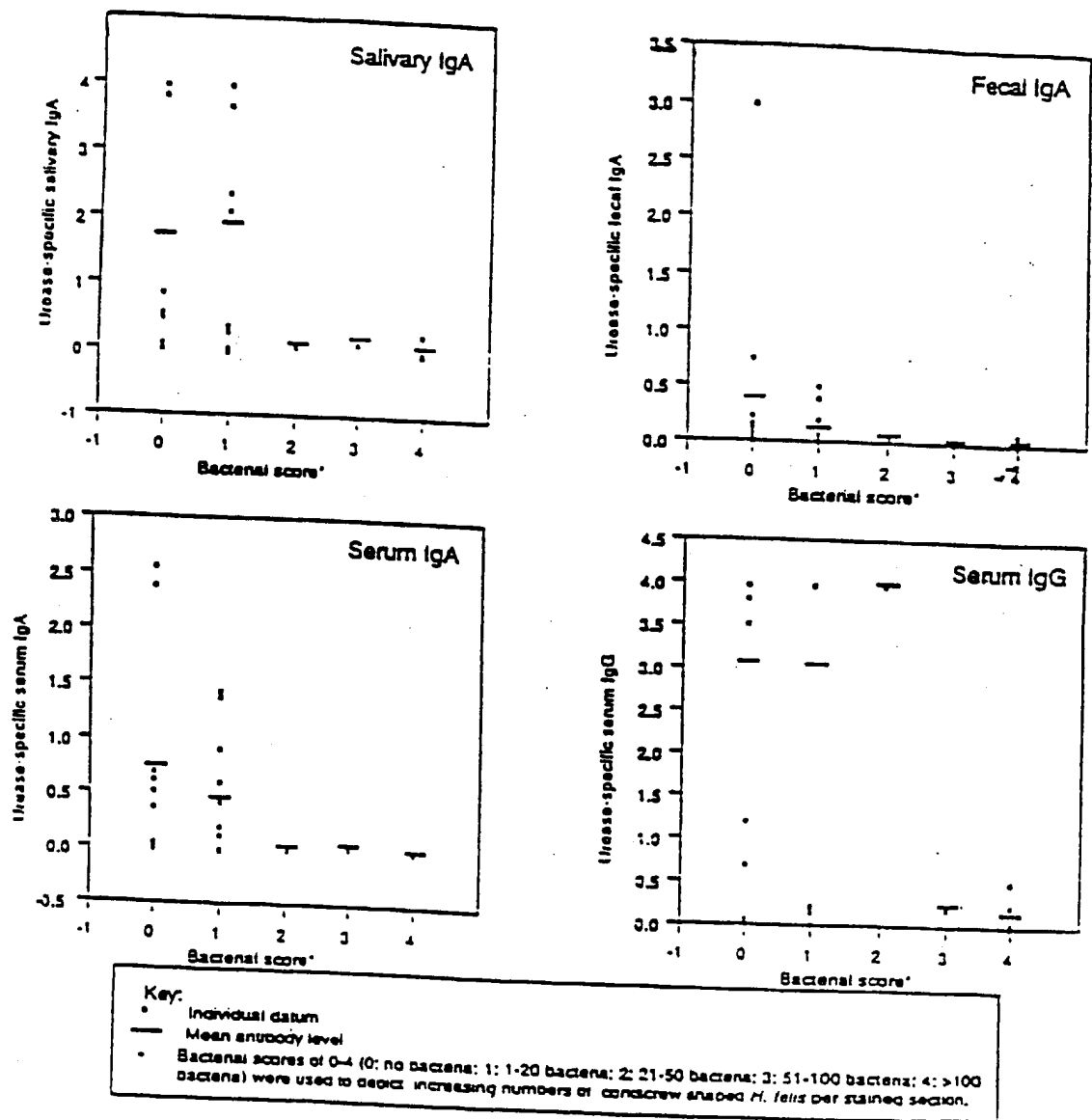




FIG. 6





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FIG. 7

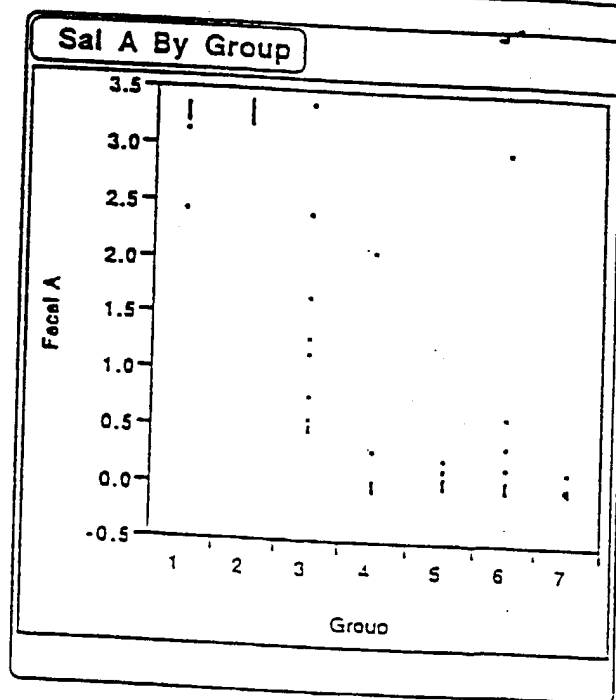
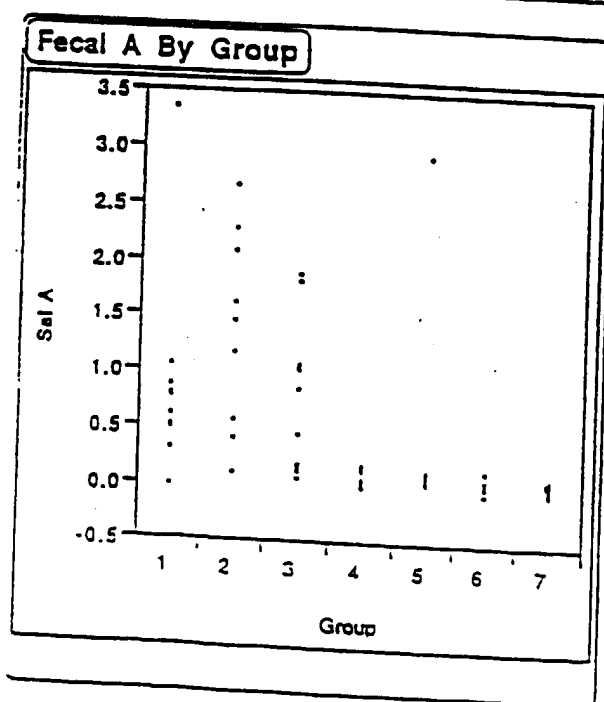
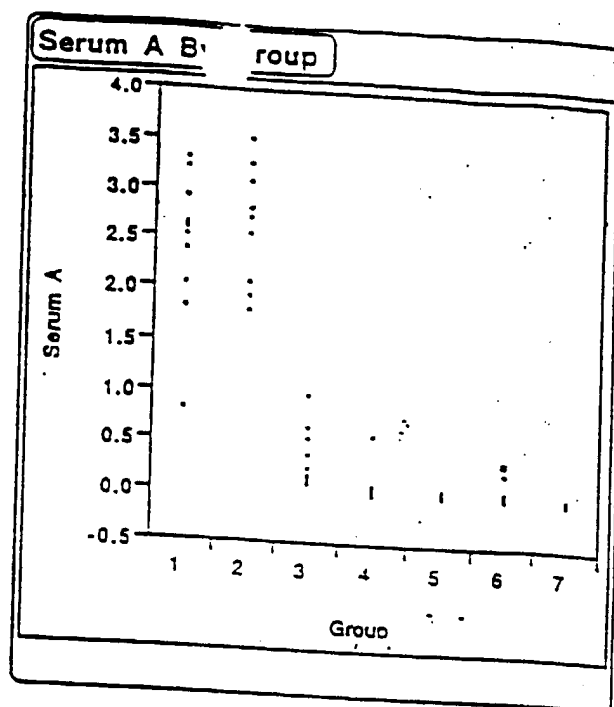
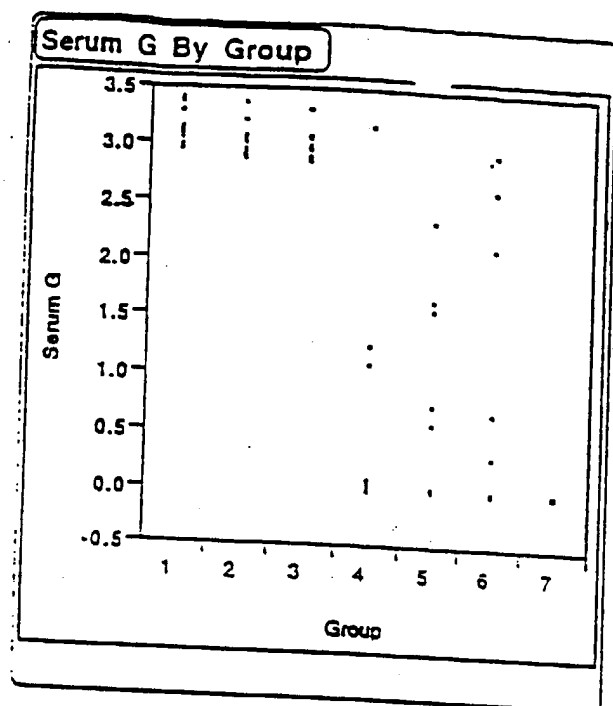
Groups	#Swi.We	Route	Antigen	CT	Tx sche.
1	10	IN	10ug rU +HCHO	No	15 x 1d (d3-22)
2	10	IN	10 ug rU	No	15 x 1d (d3-22)
3	10	IN	10 ug rU	5 ug	4 x 1W (d0, 7, 14, 21)
4	10	PO	100ug rU +HCHO	No	4 x 1W (d0, 7, 14, 21)
5	10	PO	100 ug rU	No	4 x 1W (d0, 7, 14, 21)
6	10	PO	25 ug rU	10 ug	4 x 1W (d0, 7, 14, 21)
7	10	untreated			

Blood and feces collected on day 32, and saliva collected on day 33. Challenge on day 36. Sacrifice on day 50.

(W=week; d=day)



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1 = Form-ure, IN      5 = ure, oral  
 2 = ure, IN          6 = ure + CT, oral  
 3 = ure + CT, IN      7 = no treatment  
 4 = Form-ure, oral

FIG. 8





FIG. 9

IN/oral combination. schedule of immunization

Group	n	Schedule	Sacrifice
1	10	IN days 3-7; IG days 14 and 21	2 weeks
2	10	IN days 3-7; IG day 21	2 weeks
3	10	IN days 0, 7, IG days 14, 21	2 weeks
4	10	IN + LT days 0, 7, 14, 21 (pos control)	2 weeks
5	10	no treatment (neg control)	2 weeks
6	10	IN days 3-7; IG days 14 and 21	10 weeks
7	10	IN + LT days 0, 7, 14, 21	10 weeks
8	10	oral + LT days 0, 7, 14, 21 (pos control)	10 weeks
9	10	no treatment (neg control)	10 weeks

Urease dose: IN, 25  $\mu$ g; IG 200  $\mu$ g

LT dose: IN, 2  $\mu$ g; IG

10  $\mu$ g

Challenge 2 weeks after immunization

Assays:

urease

histology for gastritis, bugs, mast cells, eosinophils

Farside assay

anti-urease in serum, feces, saliva

ASCs in stomach sections



FIG. 10

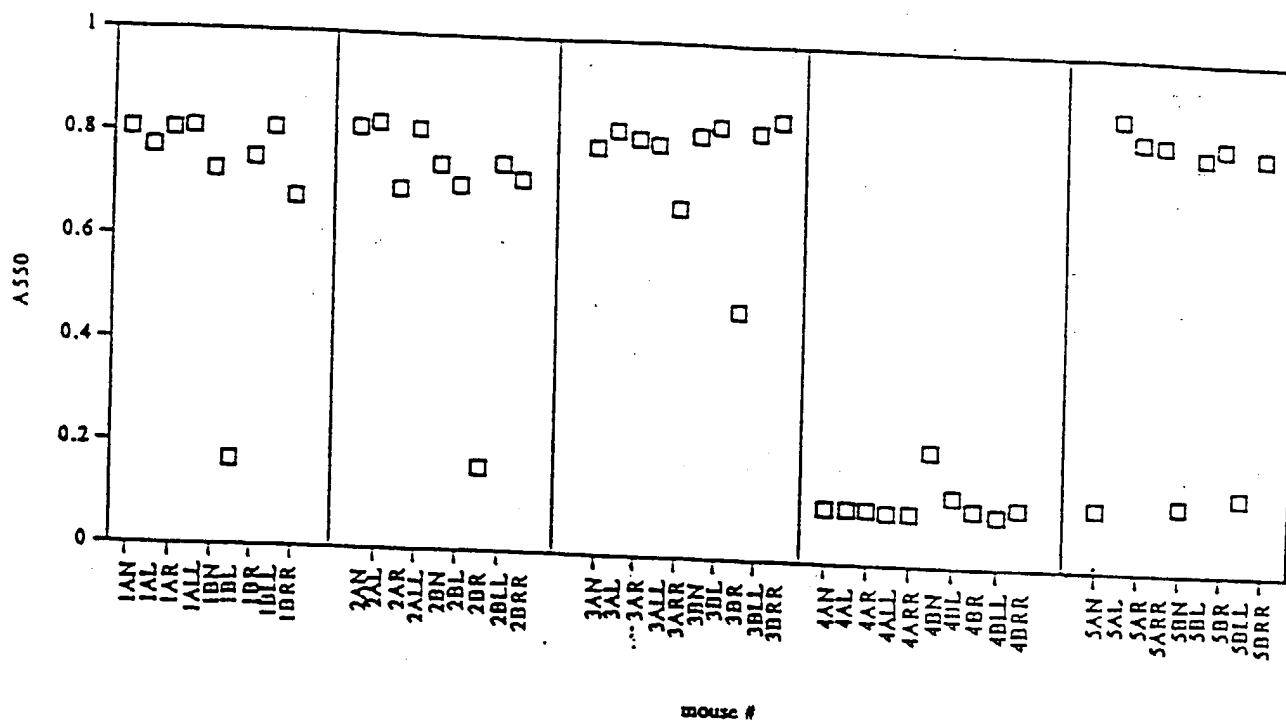


FIG. 11

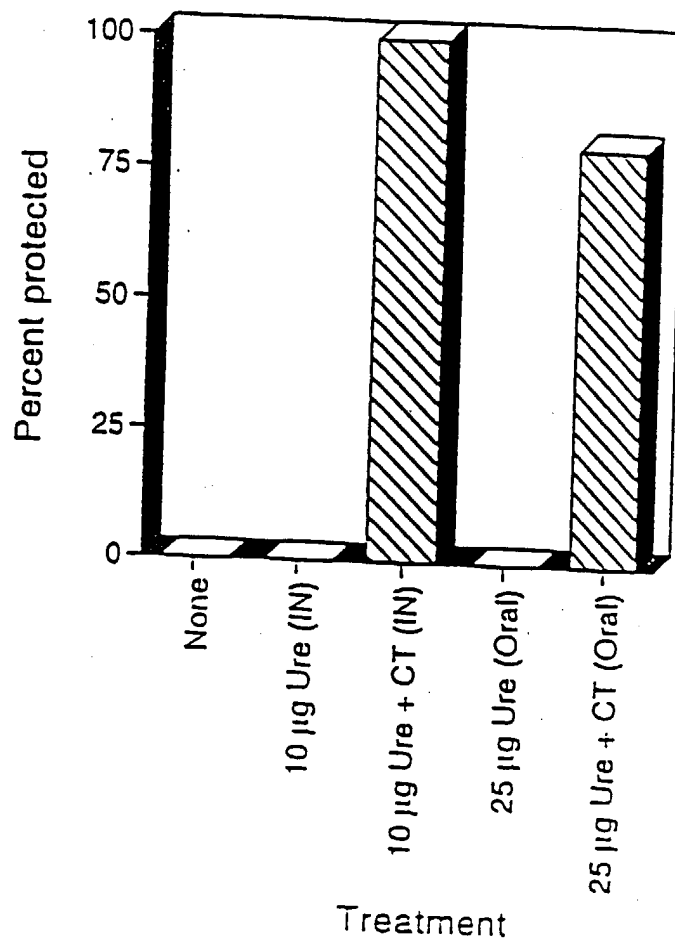


FIG. 12

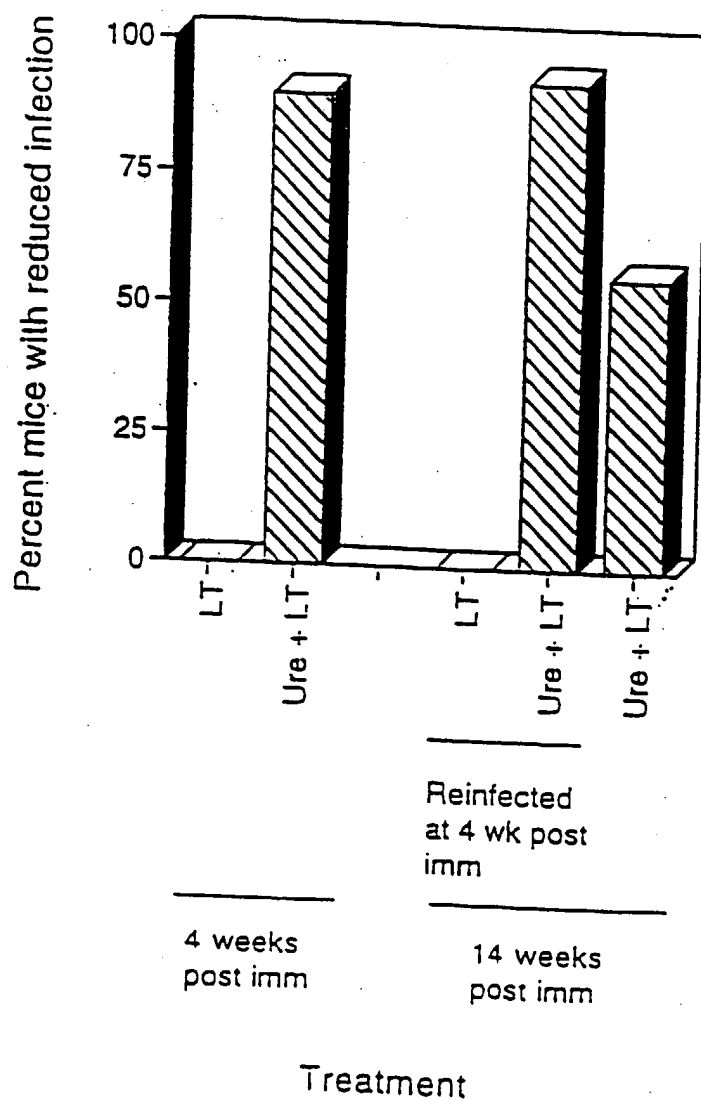
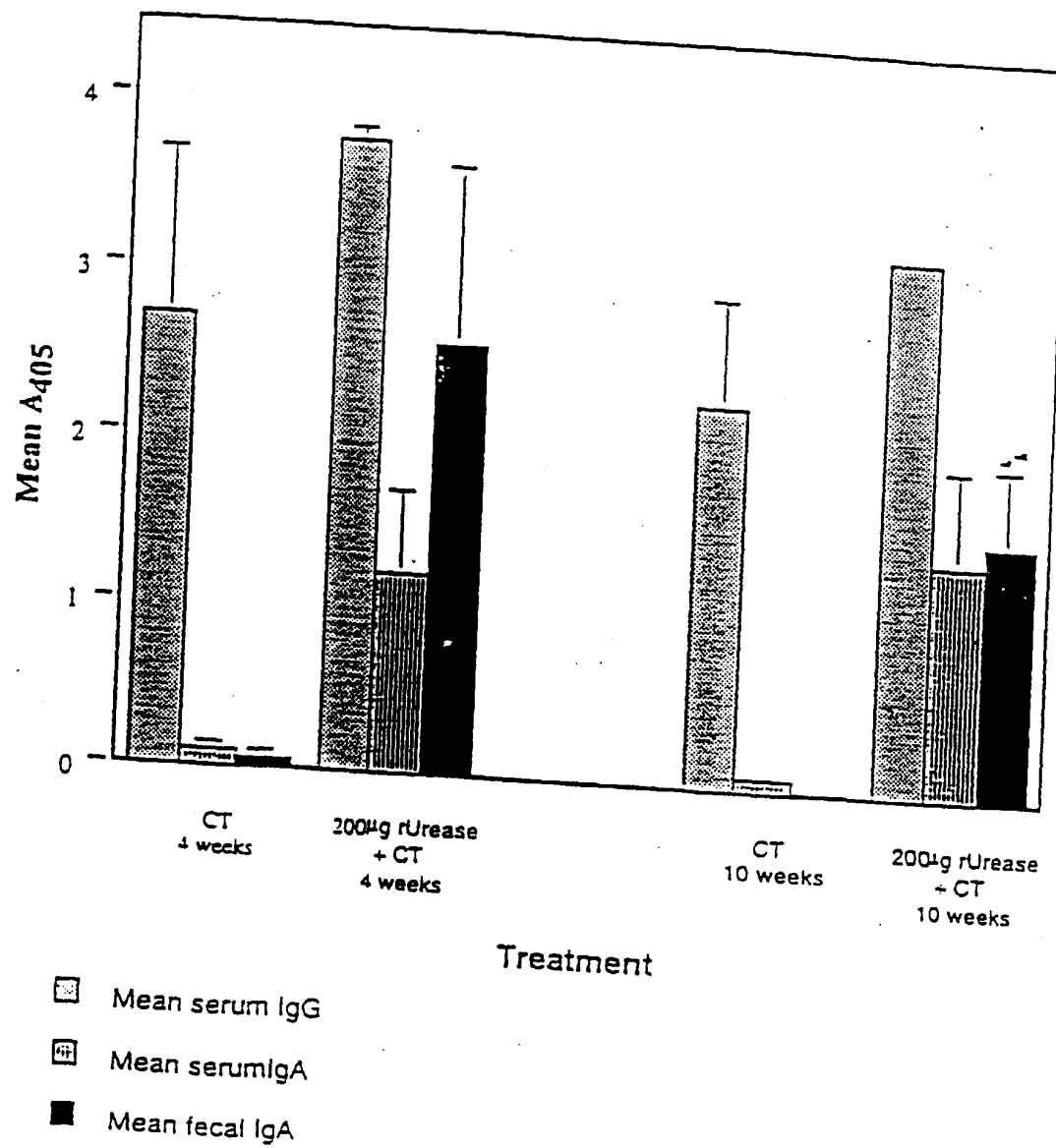
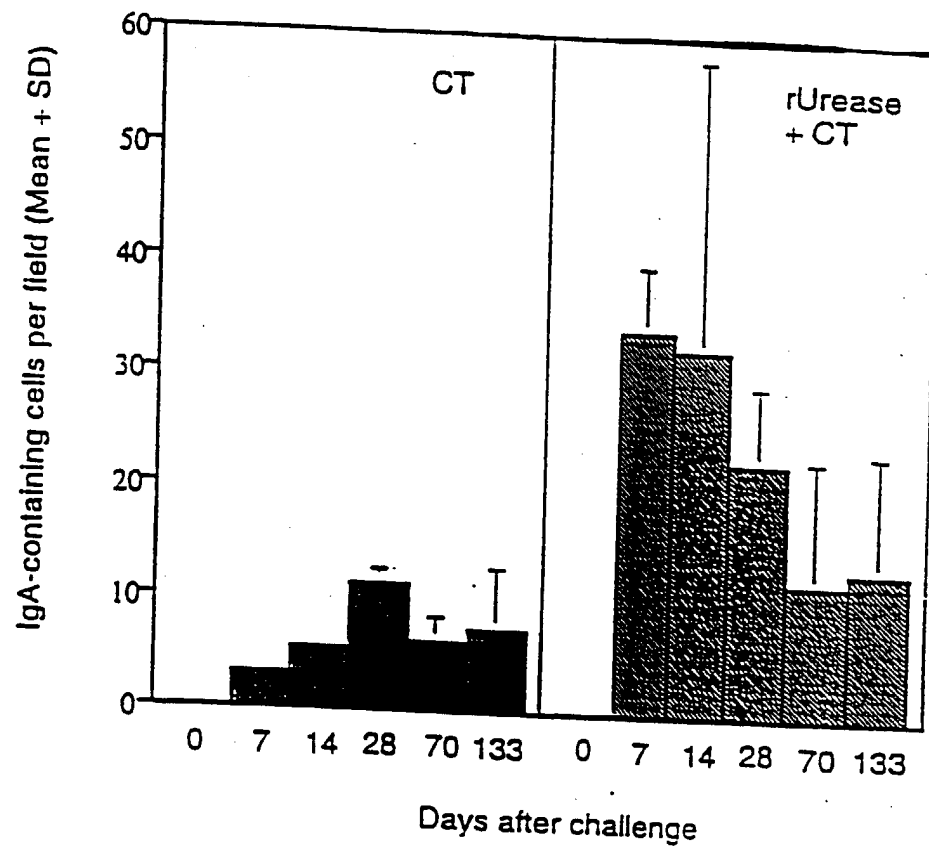


FIG. 13



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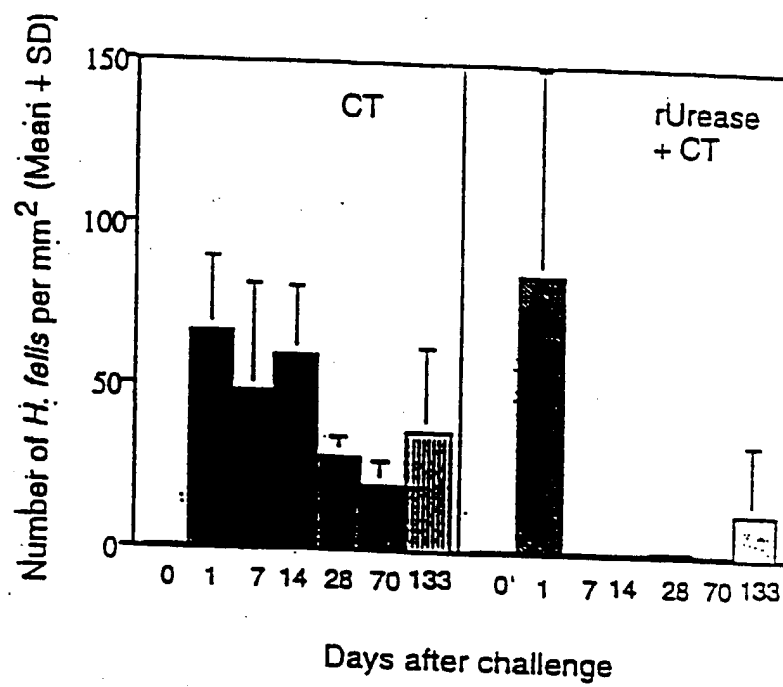
FIG. 14





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FIG. 15



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/05800

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : A61K 38/46, 39/02; C12N 9/14

US CL : 424/94.1, 94.6, 234.1; 435/195, 227

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/94.1, 94.6, 234.1; 435/195, 227

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
APS, BIOSIS, MEDLINE, EMBASE  
search terms: Helicobacter, urease, vaccine

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DAVIN, C. et al. H. pylori urease elicits protection against H. felis in mice. Gastroenterology. April 1993, Vol. 104, No. 4, page A1035, see entire document.	1-33
A	PALLEN, M.J. et al. Vaccination against Helicobacter pylori urease. Lancet. 21 July, 1990, Vol. 336, pages 186-187, see entire document.	1-33

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	* T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
* A document defining the general state of the art which is not considered to be part of particular relevance	* X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
* E earlier document published on or after the international filing date	* Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
* L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	* Z document member of the same patent family
* O document referring to an oral disclosure, use, exhibition or other means	
* P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

06 JUNE 1996

Date of mailing of the international search report

11 JUL 1996

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Washington, D.C. 20231

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